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Systems Analysis Department Annual Progress Report 1989

Edited by Hans Larsen and
Gordon A. Mackenzie

Risø National Laboratory, DK-4000 Roskilde, Denmark
March 1990

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Abstract. The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1989. The activities may be classified as energy systems analysis, risk and reliability analysis and environmental modelling. The report includes a list of staff members.

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Contents

1. Introduction

The activities of the Systems Analysis Department in 1989 involved a continuation of the research along the same lines as in 1988, i.e. with a growing emphasis on environmental questions. No major changes have taken place in 1989 regarding the overall scope of work of the department. The research and development activities included energy-economy modelling and energy planning, technology assessment, environmental planning, economic analyses of environmental effects, modelling of risk, reliability, and preventive maintenance. The research and development of the department were undertaken by the Energy Systems Group (ESG), the Risk Analysis Group (RAG), and the Environmental Modelling Group (EMG).

Postgraduate research projects form an integral part of the basic research of the department. Two ongoing projects concern methods to predict the atmospheric dispersion of accidentally released chemicals, and an analysis of the channels of interdependence between industrialized and developing countries. A new postgraduate project was initiated during the year dealing with structural dynamical modelling of aquatic ecosystems.

The Risk Analysis Group conducts research and development on methods and tools for hazard analysis, consequence modelling, and preventive maintenance. In addition, the group performs specific risk and reliability studies in collaboration with private companies and public authorities aimed at the design and operation of industrial plants.

The research and development activities of the group included continuation of the development of STARS (Software Tools for Advanced Reliability and Safety analysis) in collaboration with JRC-Ispra and others, and of the participation in a project on physical modelling of torch fires within the CEC-programme on Major Technological Hazards. Further, the group continued to participate in a number of European Benchmark Exercises.

The work initiated in 1988 within the Nordic research programme on terotechnology has been continued in 1989, and the work on risk analysis within the research programme of the Nordic Liaison Committee for Atomic Energy was completed in 1989.

During the year a number of specific risk analyses have been performed for chemical industries and offshore installations. Further, the group contributed to an overall risk analysis of the Great Belt Fixed Link.

The Environmental Modelling Group works on the development of models which can contribute to presenting a complete picture of the effect of pollution on the environment. The work of the group in 1989 has been dominated by the completion of the ECCES project, especially the application of the soil chemistry model to forest soils, and the prediction of the heavy metal content in the ecological system. Work on the RAINS model for Europe (developed by IIASA in Vienna) has been continued.

The activities of the Energy Systems Group in 1989 involved R&D concerning energy-economy models, energy and environmental planning, as well as specific studies on technology assessment.

The group collaborates closely with the Danish Ministry of Energy and the Danish Energy Agency on energy planning. The work in 1989 was concentrated on following up the recommendations of the World Commission on Environment and Development, the so-called Brundtland report.

The research and development activities in 1989 have included continued participation in the systems analysis and modelling part of the JOULE programme of the Commission of the European Communities (CEC). A project to analyze methods for integrated energy and environmental planning has been carried out for the Nordic Council of Ministers. Further, the group participates in the CORINAIR project for the CEC, DG XI.

In 1989 a comprehensive study on the consequences for energy and emissions of the Great Belt Fixed Link was completed. A number of other assessment studies have been carried out dealing with wind energy, sewage treatment plants etc.

In 1989 the department organised an international conference on Environmental Models: Emissions and Consequences. The conference took place at Risø 22-25 May. The conference was sponsored by the Commission of the European Communities. The conference addressed both the basic scientific aspects of model development and experience with applications of environmental models.

The tasks carried out by the department to a great extent involve close collaboration with industry, consulting firms, public authorities, and international organisations, e.g. the Commission of the European Communities, Nordic Council of Ministers, IIASA, UN, IEA, and WB.

In 1989 members of the department participated in a number of Danish committees dealing with questions on energy, environment, or safety. In addition, members of the department have participated in international committees within the Nordic collaboration, the IEA, and the European Communities, and have presented papers at international conferences, workshops, and seminars.

2. Risk Analysis

The work in the Risk Analysis Group covers a wide range of activities aiming at fulfilling the requirements of society and industry for risk and reliability analyses of higher and higher quality. The activities include the development of methods of analysis as well as transfer of knowledge and experience to industry and authorities. Examples of these activities are:

- development of computerized decision support system for hazard identification and systems reliability analysis,
- CEC-sponsored benchmark exercise on event sequence modelling,
- CEC-sponsored field experiments on modelling of torch fires, and
- a system for operational reliability and preventive maintenance sponsored by the Nordic Industrial Fund and the Danish Technical Research Council.

During 1989 the group was engaged in a wide variety of analyses of technical systems: overall risk analysis of the Great Belt Fixed Link, risk analysis of a water treatment system for space application, risk evaluation of jack-ups for combined drilling, accommodation and production, safety analysis of a polymerization plant, and analysis of occupational hazards in industry. The last one was initiated recently. All other activities will be described in further detail in the following chapters.

2.1. The STARS Project

The purpose of the STARS (Software Tool for Analysing Reliability and Safety) project is to develop an integrated set of advanced software tools to support the analyst working with safety and reliability analysis of chemical and power plants.

The STARS project is a collaborative project between Risø National Laboratory, JRC-Ispra, VTT (Technical Research Centre of Finland), and TECSA (Italy). Furthermore, two companies are participating in the project as affiliates.

STARS is planned as a knowledge-based approach to systems safety and reliability analysis and to represent the next generation of programs, following RIKKE (developed at Risø) and CAFTS (developed at JRC-Ispra) for automatic fault tree construction. The STARS program will be able to perform the same tasks more effectively and in addition include some new tasks.

The tasks in the STARS program comprise the identification of hazardous events and event sequences (qualitative analysis, consequence modelling, event sequence modelling, automatic fault tree construction) and probabilistic analysis.

In 1989 Risø participated in the development of the qualitative analysis module. Risø has finalized the work concerning the conceptual study and functional specifications of the chemical substance and chemical reaction knowledge bases. Furthermore, a list of generic units has been given in detail and work on the conceptual study and functional specifications of the plant/unit knowledge base has been initiated.

The definitions underlying the programmes that will implement STARS have been fairly stable for nearly one year; conceptual studies are still going on, but the implementation work has already been divided among the partners in-

volved. The STARS programme will consist of a number of fairly autonomous packages with a few large common knowledge bases. Earliest designs of such single packages have mostly been on main frame computers. STARS will run interactively and at high speed by risk and safety analysts who lack special knowledge of the computer system. The designers of STARS aim at a wide commercial distribution of the final software; this would indicate a PC solution. PCs are not powerful enough, however, so the choice has been two types of personal networking workstations, SUN and APOLLO.

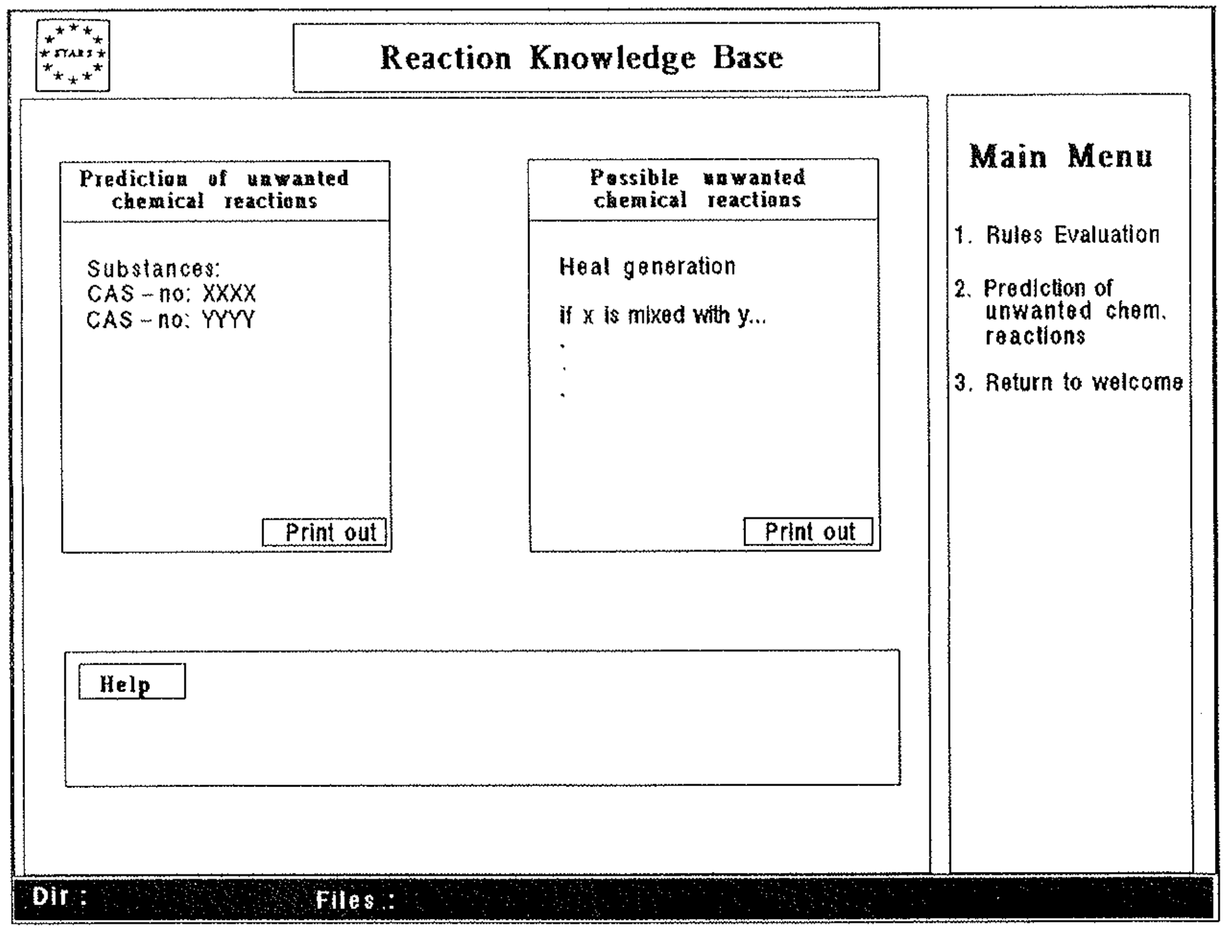
For SUN and APOLLO it has been possible to select a common software environment, X-Windows which is an emerging de facto standard for the construction of window-based programs with advanced menu and graphics facilities. X-Windows runs under the UNIX operating system; it is highly portable and expected to become available on many types of work stations.

Two aspects of the software design have been discussed with particular care, namely, the user interface and the data structure of the knowledge bases.

The end user of the software should experience a high level of uniformity in the different packages. The naming should be the same throughout, windows and menus with similar functions should look alike, and if possible the structure of stored knowledge data should be the same all over.

At Risø a few experiments have been carried out with the user interface for STARS. A full user interface for the Chemical Substance Knowledge Base and the Reaction Knowledge Base has been constructed with X-Windows. In cooperation with the design team these bases have been slightly modified. An example is shown in Fig. 2.1. This was designed with the MIT Athena Toolkit for X-Windows, which will form the future basis for the user interface design.

Figure 2.1. A typical dialogue window for the STARS Reaction Knowledge Base



2.2. Dispersion of Heavy Gas

The safe handling of pressurized liquefied gases is a recurrent issue in risk analysis. If accidentally released, most liquefied gases will form a cold heavy cloud whose behaviour is governed by gravitational slumping and suppression of turbulent mixing. Such a cloud stays close to the ground and, if not hindered in some way, spreads widely to the sides to form a shallow 'blanket' or 'pancake' very different in shape from, e.g. an ordinary smokestack plume. A fairly good parametric description can be obtained using a so-called box or slab model in the case of a uniform flat terrain, but the effects of obstacles and complicated orography cannot as yet be taken into account. These effects are not very well understood and have not been subject to much experimental investigation.

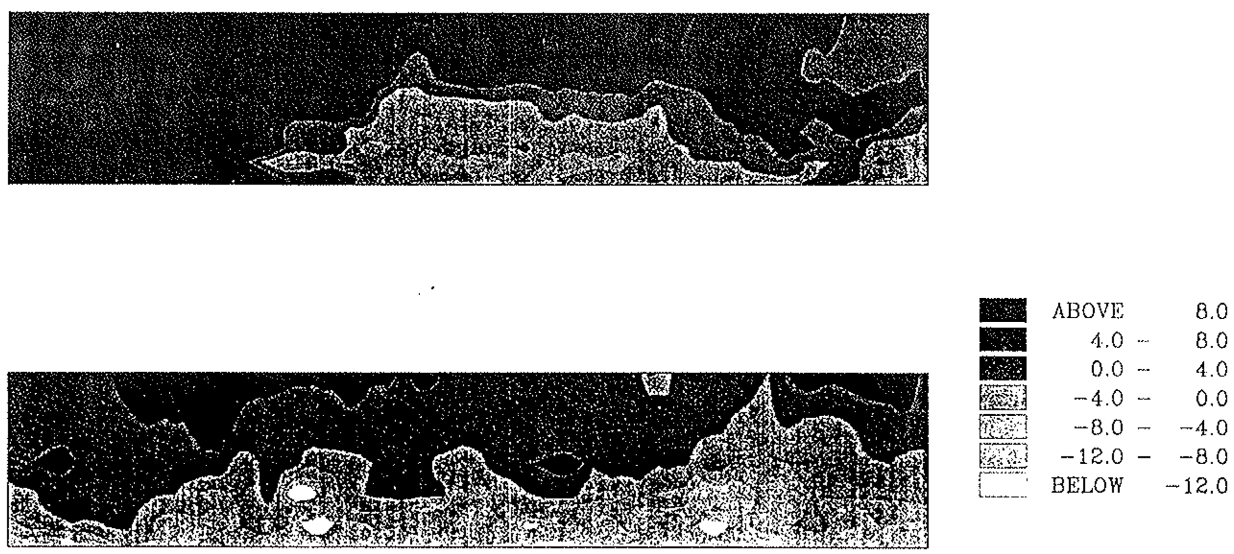
During 1989 a series of full-scale experiments was undertaken with the aim of studying the effect of simple geometric obstacles on the spreading and dilution of dense propane clouds. The experiments were carried out by a group formed by the Meteorology and Wind Energy Department together with the Systems Analysis Department at Risø in collaboration with a group from Techniches Überwachungs Verein, Hamburg, who operate a propane test facility near the town of Lathen in West Germany. The trials form part of the BA project under the CEC research programme on the topic of Major Technological Hazards and they were made during two 4-week periods in May and August 1989.

In the experiments liquid propane at ambient temperature and pressure 10-bar was released continuously at rates ranging from 2 to 6 kg/s into a flat terrain where artificial obstacles in the form of 2-m high fences had been erected. The fences were constructed so that they could be made to collapse easily to allow a comparison to be made between the obstructed and unobstructed plume keeping the meteorological conditions fixed. Various geometries were used: a 60-degree 48 m radius arch, a straight line fence, and a 4 m wide channel with the source located at one end or to the side. In most cases the obstacle was located downwind relative to the source, but the opposite configuration was also tried.

A large number of ground-based propane concentration sensors were placed in a formation somewhat wider than the anticipated extent of the cloud, and four 6-m high masts were erected to make profile measurements of wind speed, temperature, and propane concentration inside and outside the cloud. Risø was responsible for these masts. Typically a mast would be equipped with three cup anemometers, one wind vane, three catalytic type propane sensors, eight thermocouples, and three thriple axis ultrasonic anemometers.

An example of data obtained by means of the thermocouples is shown in Fig. 2.2, which indicates the thermal structure of the cloud as seen from a vertical array of thermometers. As the cloud sweeps past, the sensors record a relatively faithful image of its spatial structure so that the figure can be regarded as describing a slice of the cloud coming in from the right. The temperature is found to be a good indicator of propane, so the cold parts of the cloud coincide with high-concentration regions. On the upper strip the arrival of the sharp front edge is seen along with the characteristic dense cloud 'nose' (front vortex). On the lower strip large eddies with cold centres are seen. It was observed visually and recorded on tape that roles are formed near the source where the propane jet hits the ground. These roles are generated at fairly regular intervals, extend right across the plume, and turn in a direction opposite to that of a rolling wheel. As they travel downwind they gradually fade out into chaotic turbulence. Undoubtedly the larger eddy structures play a dominant role in the mixing of propane with air, so it is essential that the instruments operate sufficiently rapidly to resolve them if this process is to be studied more closely. It is anticipated that the data will prove useful when future models are tested.

Figure 2.2. Thermal structure of a dense, cold propane cloud obtained from a vertical array of thermocouples. The strips cover 6 m by 16 seconds each. Shades of gray have been assigned to temperature intervals.



A new high-speed technique for measuring propane concentrations has been developed. It is based on combined measurements of temperature and sonic speed using a thermocouple and an ultrasonic anemometer. From the readings of the two instruments it is possible to deduce not only the propane concentration but also simultaneous values of the three wind speed components within a relatively small measuring volume (30 cm). From such data, average fluxes of propane and enthalpy can be calculated and compared with theory.

Figure 2.3 shows three concentration series calculated from thermocouple and sonic data. The probes were positioned at three different hights on a mast located 14 m downstream of a straight-line fence. Behind a fence a large vortex is formed and it was expected that this would give rise to additional mixing. In this way concentration levels ought generally to decrease as well as become more fluctuating compared to the case without an obstruction. After an elapsed time of 320 seconds the fence was removed, and it is then seen that the concentrations are affected differently at different heights. With regard to the top of the cloud the concentration is decreased as the fence is collapsed while at the bottom the concentration is slightly increased. With regard to concentration fluctuations, the influence of the obstacle is again ambiguous: at the top of the cloud fluctuations are enhanced by the presence of the fence, but at the bottom they are damped. It seems inevitable that a fairly complex dynamical model that takes into account the effects of roles and of the lee vortex is needed in order to explain the data quantitatively.

A PC-based gas dispersion program package has been under development. The package contains a model describing the failure of a pressurized tank, a puff model, and a plume model for depicting dense gas dispersion in flat terrain, jet models covering gaseous released and releases of condensed gas (flashing jet), and models for various cases of two-phase pipe flow. The jet model was compared with experimental results from vertical propane releases. Here the jet bends over and sinks to the ground because of gravity, and it was found that the model quite accurately predicts the maximum height, the point where the plume makes ground contact and the concentration at that point.

In connection with a Ph.D. study an investigation into the theory of turbulence and turbulent diffusion was made. A systematic perturbation theory was established for Navier Stokes turbulence and for problems of turbulent diffusion. The perturbation series can be cast in a form which closely resembles that of a quantum mechanical gas of interacting bosons, and a diagrammatic interpretation of terms can be given in analogy with the Feynmann graphs used in quantum field theory. Within this framework, methods of closure can be seen as partial resummations of the perturbation series. Thus the single-loop renormalization leads to Kraichnan's Direct Interaction approximation for the turbulence problem and to the method known as Corrsin's conjecture for turbulent diffusion. The first of these methods is known to fail for strong turbulence (which is the case for the atmosphere) and it is shown that the same is true for the latter. It is argued that the failure is caused by an improper handling of Gallilean invariants, and a new method is proposed.

This method is based on a rearranging of the perturbation so that terms are collected in groups which are Gallilean invariants, and it is shown that this removes certain troublesome divergencies. The method is applied to turbulent diffusion and it is found that acceptable results can be derived for the cases of absolute and relative diffusion in homogeneous isotropic turbulence. It is hoped that the method can be extended to more complicated situations such as that of diffusion in a shear flow and diffusion in a density gradient (with obvious applications to dense gas dispersion).

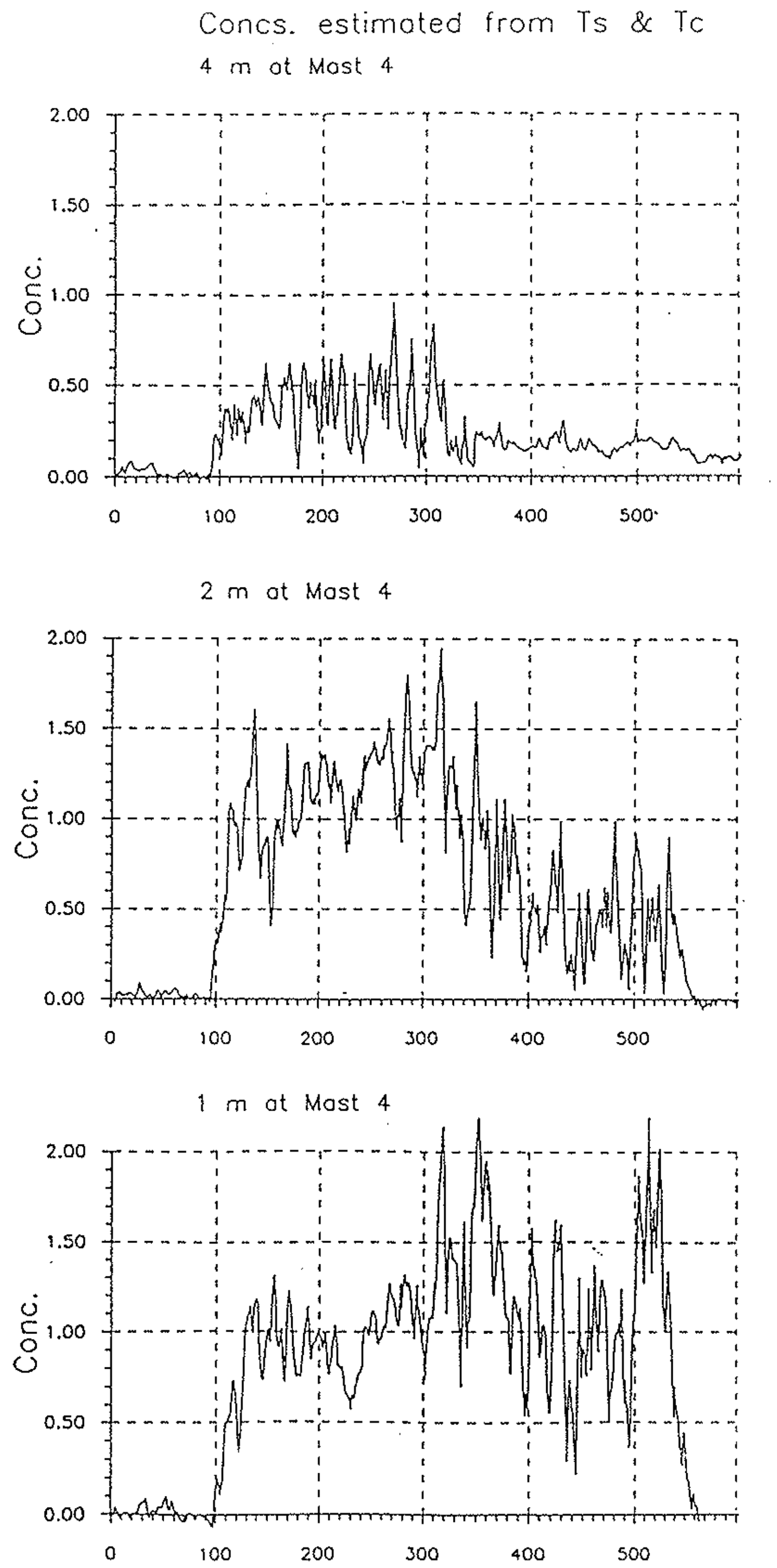


Figure 2.3. Propane concentration time series obtained from data from sonic anemometer and thermocouples. The concentrations are in volume per cent and the time in seconds. The probes are located 14 m downstream of a 2-m high fence. After an elapsed time of 320 seconds the fence is removed, producing a rather surprising impact on the concentration levels and the fluctuations.

2.3. Terotechnology

A Nordic Research Programme on terotechnology was initiated in 1988. The programme is divided into four research areas:

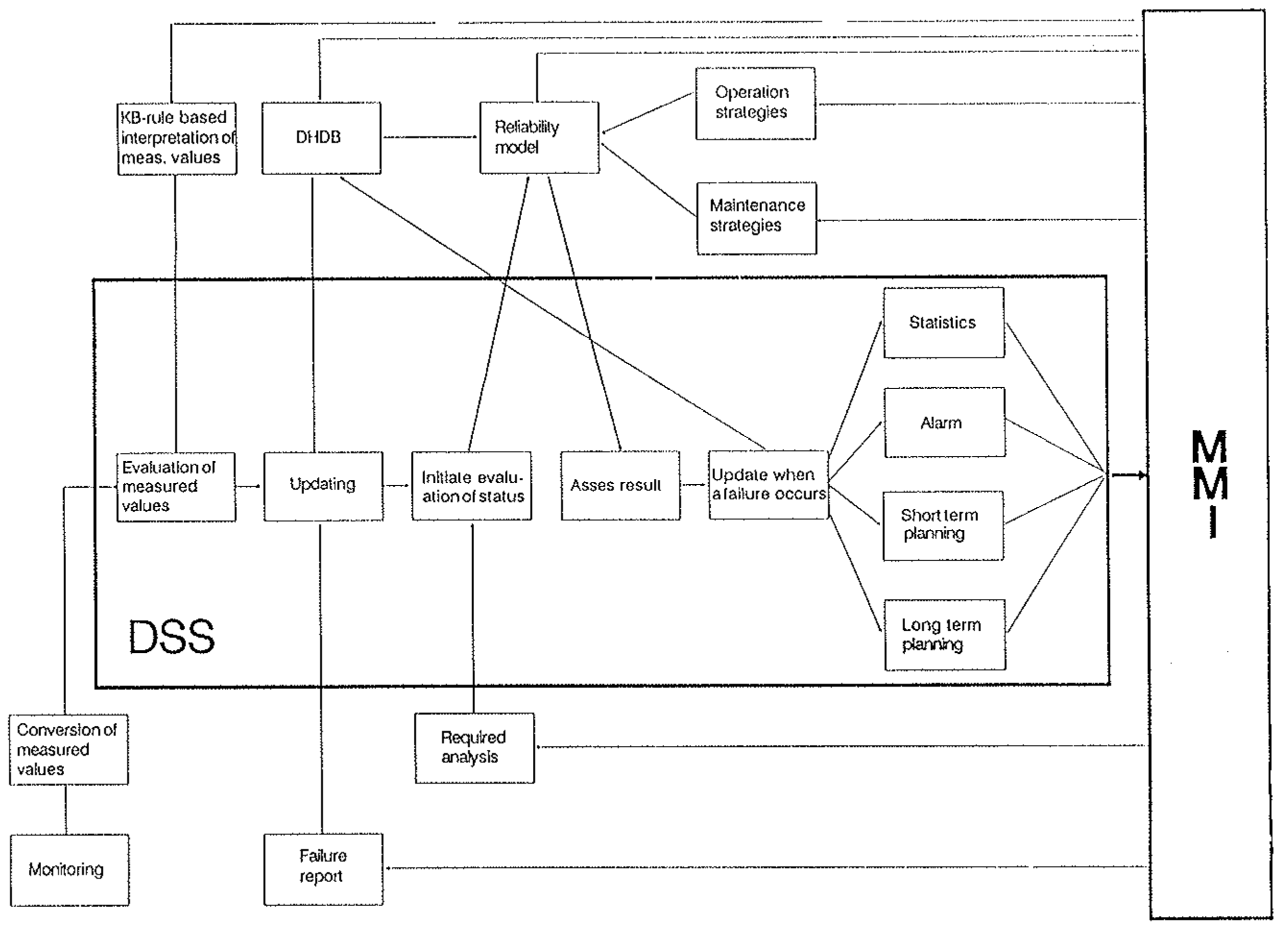
- Accelerated Testing
- Failure Data Information
- Condition Monitoring
- Availability Performance Assurance.

A total of 16 individual Nordic projects are included in the programme, of which two are performed by Risø, both within the last-named area on Availability Performance Assurance.

In 1989 a concept of an integrated decision support system for maintenance planning was developed (see Figure 2.4). The central idea is the application of a reliability model of the plant as a basis for evaluating the system state in case of disturbances or failures; information on these is collected from failure reports or maintenance logs either requiring in many cases restructuring of the reporting systems used or the monitoring system. The latter consists of two types of data. Equipment for some purposes is available for monitoring the condition of the system, and can be used directly as a source of information. In general, only the traditional control and measuring systems giving information on temperature, pressure, flow, etc. are installed. The idea is to develop a module which is able to treat this kind of information and combine single signals to assess a malfunction or an emerging problem.

The results of the analysis can take the form of statistics regarding the distribution of failures over time for a given component or class of components. Further, a number of possible statistical tests will be provided to study significant changes in expected component failure rates or repair times components. For planning purposes two kinds of recommendation are proposed: The first concerns short term planning, where a list of components or systems to be tested or repaired during a given plant shutdown will be provided. This arrangement is called occasional maintenance planning, and has a strong economic interest, particularly within offshore industry and shipping.

Figure 2.4. Structure of the knowledge-based system for maintenance planning.



The long-term planning consists of recommendations concerning the planning of test or replacement intervals. Based on the schedules and the failures and disturbances observed, plans are updated accordingly.

Special emphasis is put into the treatment, selection, and presentation of the results for persons at different positions within an organisation, such as maintenance staff, maintenance planners, managers, etc. with the purpose of gaining assurance that the correct information is presented to the proper persons. This part is very important for industrial applications of the system, since information that is either lacking or overwhelming will significantly limit its benefits.

The project work will continue with the development of a set of performance indicators which describe the expected state of the system and which can be used for assessing the changes in a system state in the event of failure.

2.4. Risk Analysis, NKA

Risø participates in the project "Risk Analysis" within the Nordic Liaison Committee for Atomic Energy (NKA) Research Programme. The project which was initiated in 1985 has the following objectives:

- To review and evaluate the current state of PSA-techniques with special emphasis on the treatment of dependencies, human errors and uncertainties. This process should lead to the identification of significant differences in analytical approaches of selected PSA-studies.
- To investigate the sensitivity of results obtained from PSA-studies to basic assumptions, to data assignments and to choices of methods for analysis of selected topics.
- To identify weak points and suggest improvements of approaches that have been put into practice.
- To exchange new ideas and supply methodological support to current and planned projects related to the topics mentioned above.

The objectives were met by studies of common cause failures, human interactions and uncertainty analysis.

In 1989 work was concentrated on two subjects:

- completing of a study on the treatment of uncertainties, and
- final report writing and editing.

The benchmark study on the treatment of uncertainties is carried out with aim of evaluating the impact of data uncertainties. An accident sequence combining 18 basic failure events is specified. Computer codes for uncertainty propagation are compared using this sequence. An example where a log-normal distribution is fitted to data for each basic event, is shown in Figure 2.5 for mean value and standard deviation for the four different Nordic participants. It is seen that many simulations are required before reasonable convergence and agreement are achieved.

The final report is under preparation and will be issued in April 1990. Special findings of the project are:

- impact of alternative methods, data and assumptions in modelling of Common Cause Failures (CCFs) and human interactions on the results of current PSAs,
- use of systematic procedures for search and quantification of CCF-contributions,
- modelling of critical operator interactions in view of differences in boundary conditions, and
- alternative approaches to treatment of uncertainties, comparison of computer codes for uncertainty propagation, and decision-making in view of uncertainties.

2.5. Hazardous Materials

A research project concerning combustion of chemical substances and the impact on the environment of the fire control methods has been initiated. The purpose of the project is to be able to predict and quantify the toxic substances that are generated in the event of a fire in a storage facility for chemicals, for example, and to model the dispersion of the plume.

A search in the accessible literature was made and a data base with relevant references on the subject has been constructed. Pilot experiments have been carried out in the laboratory in order to develop an experimental set-up, and a combustion furnace for small scale experiments (i.e. combustion of 0.1 to 1 g substances) has been constructed. Finally, methods for qualitative and quantitative analyses of the combustion products have been studied.

In 1990 a Ph.D. study will be inititated. The project will include animal experiments aimed at assessing the toxicological effects of the fire products.

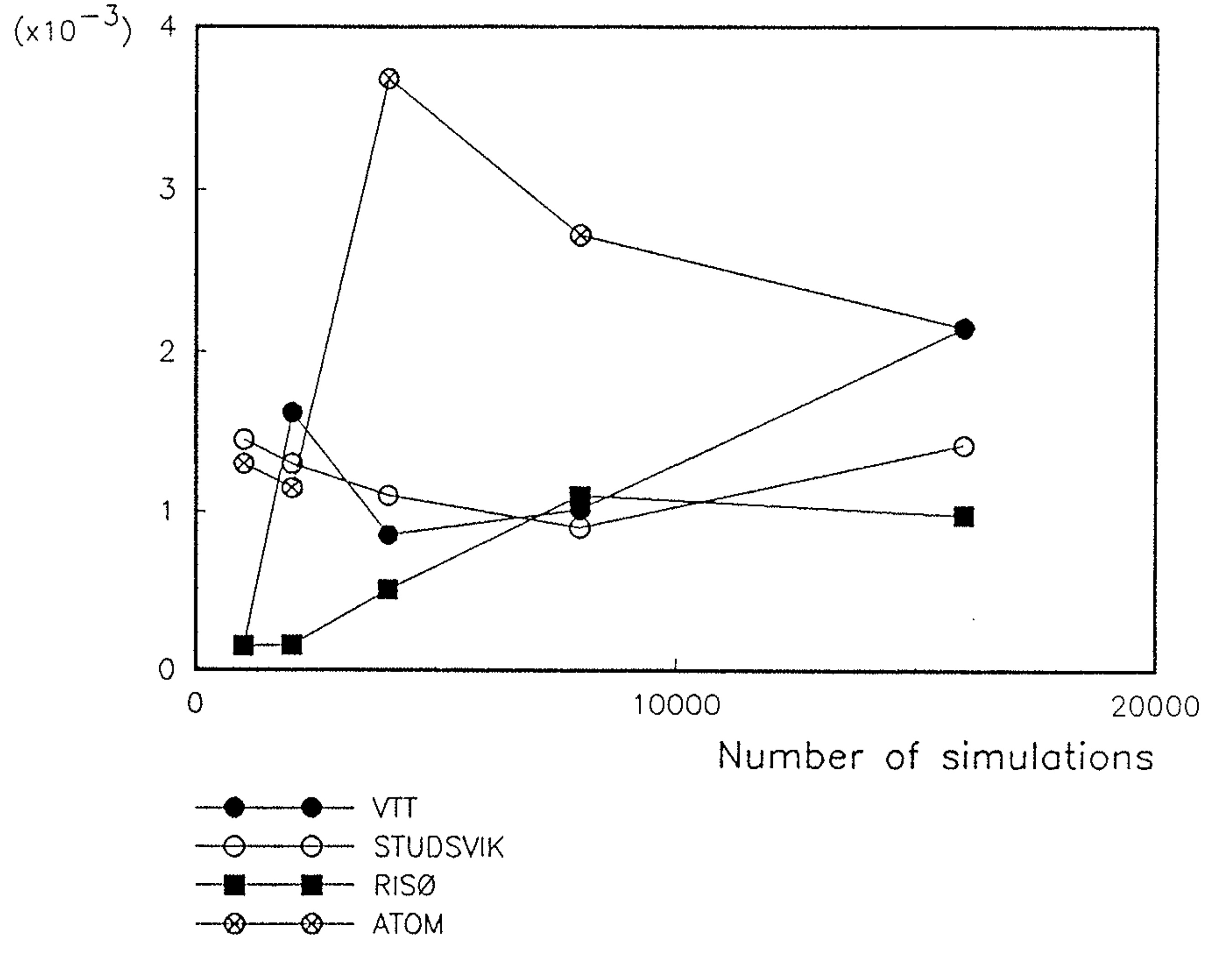


Figure 2.5. Standard deviation as a number of trials for each participating team.

2.6. Risk Communication

Public discussions arise from time to time on the risks associated with specific industrial plants. Plant owner, worker, neighbour, and risk expert may evaluate the risk differently. People's attitude to questions of risk, influenced to a great extent by personal experience and interests, and a great deal of knowledge about risk has been gathered from the news media. Such knowledge is often tied to specific cases and accidents, and may not necessarily lead to a balanced perception of risk.

The Risk Committee of the ATV (Danish Academy of Technical Sciences) is working on the promotion of Danish risk research and risk management.

The idea of working out a set of compendia on risk, risk assessment, and risk communication grew out of discussions in the Risk Committee. The ATV requested Risø to carry out this task, and the project was initiated at the beginning of 1989. The material will present and discuss the most important aspects of risk to individuals and society. This includes a review of typical accidents, measurements of risk, risk analysis, and risk control. It also includes a treatment of human factors and acceptance criteria, as well as a discussion of the attitudes of society and the individual to risk.

The material will consist of seven text modules, six of which have already been prepared by specialists selected by ATV. One module has been selected for test in a high school, supplemented with 28 slides and a set of problems. The test was conducted in the last two months of 1989, and preliminary test results are scheduled for January 1990.

It is intended that the educational material should communicate a fair amount of knowledge about actual levels of risk, against which one may compare projected risks. It is also hoped that it may improve a person's ability to make a rough estimate of one risk in relation to another and to choose among several risks. The project should be completed in 1990, and the results will be presented to teachers in a seminar late in 1990.

2.7. Offshore Oil and Gas

The Risk Analysis Group has extensive experience in safety related investigations at offshore installations. This year the work was concentrated on two major studies: evaluation from platforms in emergencies and safety considerations regarding jack-up based drilling,oil and gas production, and accommodation.

Following the Piper Alpha accident in the British sector of the North Sea in July 1988, an investigation concerning the risk to personnel on British platforms was initiated by the British authorities. The Risk Analysis Group contributed to a British study as a subcontractor.

Assessment of the probability of successful evacuation in case of an accident. Five different accident scenarios were evaluated:

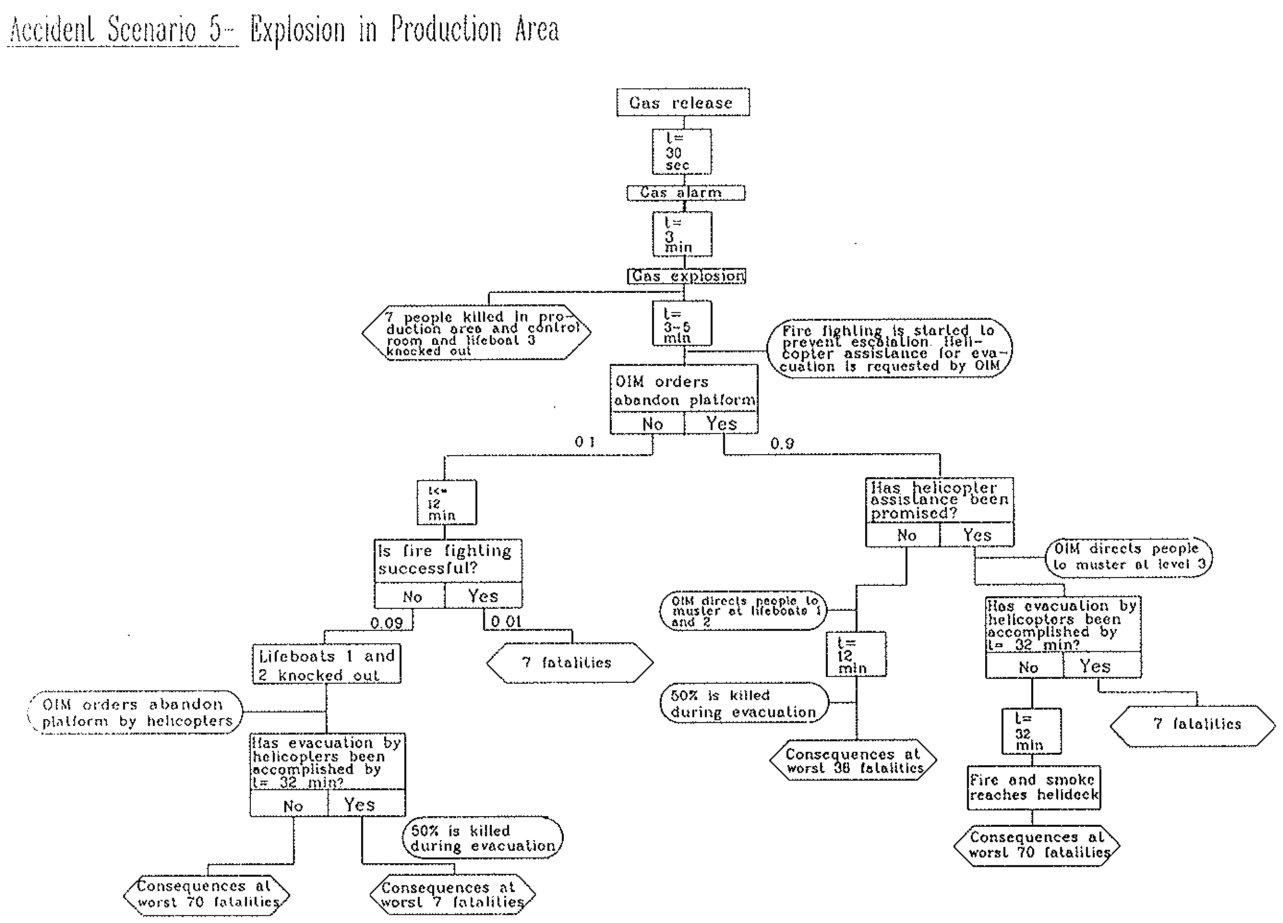
- fire in an accommodation block
- major oil pool fire on the sea
- drilling blowout
- major fire in a production area, and
- explosion in a production area.

The evaluation is based on detailed event sequencies with respect to time and extent of damage.

Evacuation possibilities are evaluated by means of a cause/consequence diagram shown in Fig. 2.6. The diagram reflects the distribution of people and the location of lifeboats, liferafts, and the helideck as well as the important actions and decisions to be taken by the Offshore Installation Manager (OIM).

The evaluation shows that it is very important that the OIM makes the decision to abandon the platform at a very early stage, i.e. that he realizes that a catastrophic accident is underway. Furthermore, the presence of helicopters at or close to the platform is important, since evacuation by helicopter is the preferred means of abandoning the platform.

Figure 2.6. Cause/consequence diagram for an accident involving an explosion in the production area.



In collaboration with Rambøll & Hannemann and Technip (France) a feasibility study was made concerning the use of a jack-up based drilling, production, and accommodation system. The study was conducted on behalf of Statoil Efterforskning og Produktion a/s (Norway).

On the basis of a number of defined parameters concerning field location, water depth, production rate, oil prices, etc. the prestudy evaluates the following aspects:

- previous experience with jack-up based drilling/production systems,
- limiting parameter,
- field development scenario,
- safety aspects, and
- economic viability.

Firstly, it was noted that the Danish guidelines for personnel safety, etc. do not refer explicitly to jack-ups. The regulation requires however that well heads and quarters must be placed on separate units unless special circumstances preclude this.

On the basis of a preliminary assessment of experience from a number of typical accidents, we have concluded that a jack-up based system can be designed so as to resemble a traditional jacket based field development solution (as seen on the Danish continental shelf) with respect to safety. The acceptability of a jack-up based system, however, should usually be based on a safety evaluation of the specific design. This evaluation should in turn refer to the guidelines in the regulations of the Norwegian Petroleum Directorate.

The overall conclusion of the prestudy was that a jack-up based system is technically feasible and economically viable for the field development parameters that have been defined.

2.8. Risk Analysis of Chemical Industry

2.8.1. Hazard Identification at Plant Level

Hazard identification of chemical process plants can be carried out at unit or plant level. Methods exist for hazard identification at unit level, but for large chemical process plants the time consumption using these methods can be tremendous; furthermore it can be very difficult to establish a risk survey for the plant as a whole.

Methods for hazard identification at plant level include the Dow index and the Mond index. The advantages and limitations of these indices have been evaluated by analysis of three chemical process plants: a reforming plant, a fine chemical plant, and a fertilizer plant, the latter being a combined nitric acid plant and ammonium nitrate plant.

The outcome of a Dow analysis is a fire and explosion index. The results from a Mond analysis are expressed in four index values: fire, internal explosion, aerial explosion, and overall risk. Some of the results are shown in Figures 2.7 and 2.8.

Figure 2.7: The reforming plant shows good agreement between the identified hazards of the process units when applying Dow and Mond indices. However, some discrepancies exist with regard to the hazard ranking of the compressor unit:

- the Dow index assigns a high hazard level to hydrogen, and
- the Mond index assigns a negative penalty factor to hydrogen with the explanation that hydrogen is a low-density gas which in the event of a release disperses very quickly into the air so that a low ignition probability can be expected.

The different ranking of the compressor unit has been discussed with the plant staff, and in their opinion the Mond hazard ranking is the most proper assessment.

Figure 2.8: The nitric acid plant shows that the ammonia cold storage tank is the most critical unit in the plant. This conclusion has been discussed with the plant staff and it is in accordance with their own estimate of plant risks. The argumentation of the staff differs, however, from the principles in the Dow/Mond manuals. According to the Dow/Mond analyses, the high risk ranking of the ammonia cold storage tank is due to the fire risk. The staff hold a contrary view, namely, that loss of containment with release of ammonia is the most important cold storage tank hazard.

From the three analyses that use Dow and Mond indices, some general conclusions were drawn:

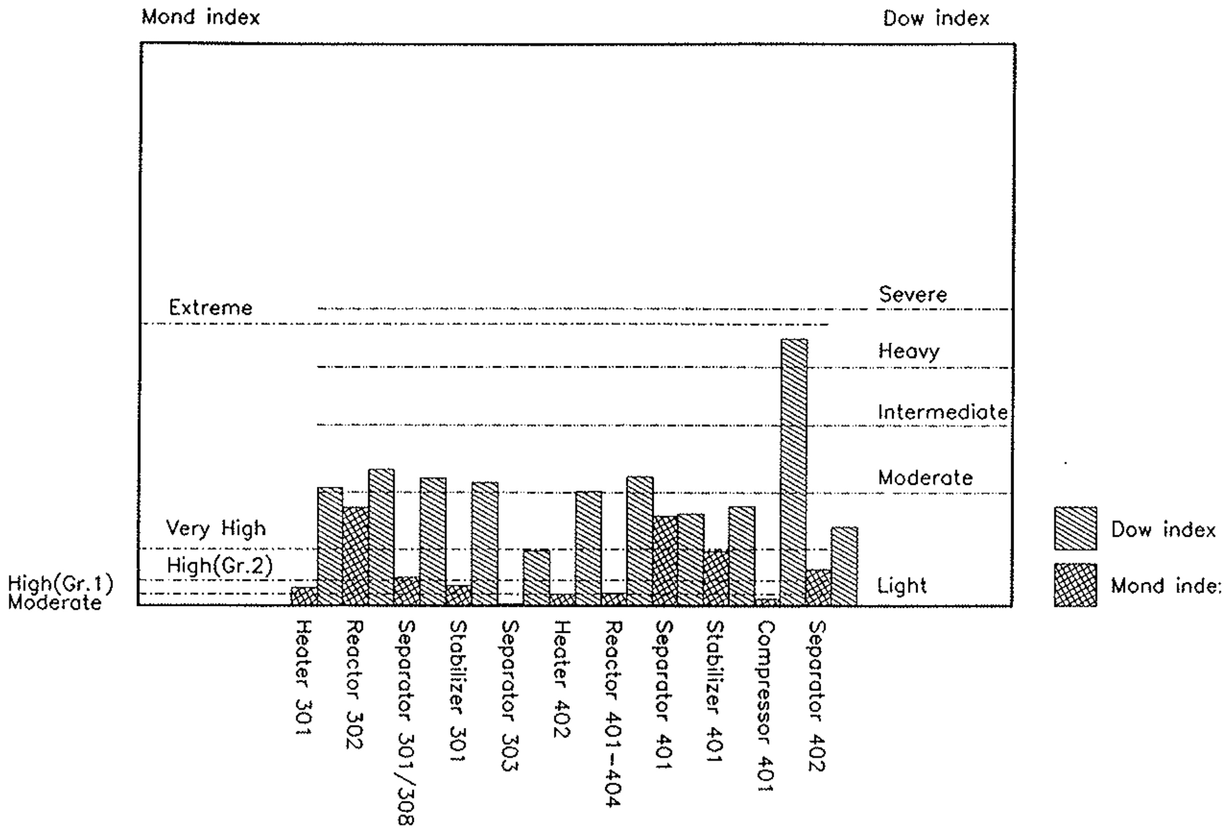
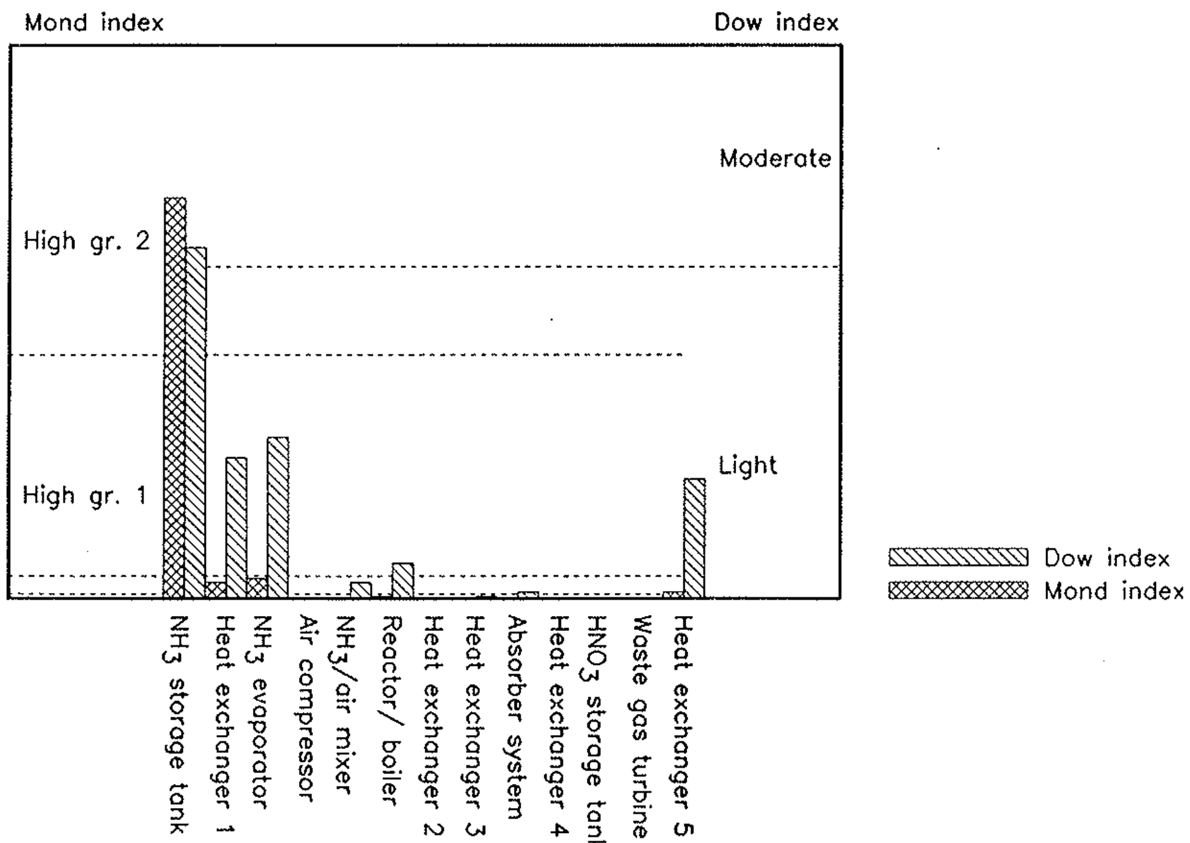


Figure 2.7. Dow index and overall index (Mond) for the main units in the reforming plant.

Figure 2.8. Dow index and overall risk index (Mond) for the main process units in the nitric acid plant.



- Hazard rankings: The results showed good agreement between those found by use of the Dow and Mond indices and in general the plant staff agreed on the hazards identified that were and their levels.
- Failure propagation: This important contribution to plant risk is included neither in the Dow nor the Mond index and to complete the hazard identification it is necessary to perform a failure propagation analysis in parallel with a Dow/Mond analysis.
- Toxicology: The Dow and Mond indices have been developed to identify fire and explosion risks. One essential limitation is therefore that for process units that handle highly toxic substances such as the ammonia cold storage tank, the correct risk level is not found.

2.8.2. Risk Analysis of an Acrylic Sheet Production Plant

In 1989 the Risk Analysis Group performed a risk analysis of an acrylic sheet production plant. During this process methyl methacrylate is polymerized to polymethyl methacrylate. The analysis comprised technical descriptions (topography, equipment, procedures and materials), hazard identifications and consequence evaluations.

The most important hazard identified was the release of methyl methacrylate. Possible causes for such releases include a runaway of the polymerization reaction, improper connection of hoses to filling tubes, and overflow from the reactor. If the release occurs indoors, a toxic atmosphere can be generated or if the vapours are ignited a "confined vapour cloud explosion" will result.

2.9. European Reliability Benchmark Exercises

2.9.1. Benchmark Exercise on Major Hazards Analysis

The benchmark exercise concerns the study of major hazards associated with the operation of a chemical plant. The exercise was started in early 1988 under the Shared Cost Action programme of the Commission of the European Communities, and teams from Belgium, Denmark, Finland, Germany, Greece, Italy, The Netherlands, UK, and Spain participate.

Danish participation in the exercise takes the form of a joint venture between Risø National Laboratory, Cowiconsult Consulting Engineers and Planners A/S, OC Consulting Engineers and Planners A/S, and Computational Safety and Reliability.

The first working phase was reported in late 1988. The second and final working phase began early in 1989 and concerned the study of a set of accident cases that released and dispersed of ammonia. With common assumptions adopted for meteorological conditions and release conditions (break sizes), the study included:

- calculation of NH_3 release rate versus time,
- calculation of NH_3 concentration versus downwind distance at 5 min intervals after the accident, see Fig. 2.9,
- determination of risk contours by use of various vulnerability models, and
- probabilistic analyses.

The second phase of the study was reported in mid-1989. The Joint Research Centre, Ispra, has compared the results of the various teams to investigate how the results vary with the choice of models. This comparison and that of the results of the first working phase will be published in mid-1990 together with summaries of working reports.

2.9.2. Event Sequence Reliability Benchmark Exercise

A reliability benchmark exercise concerning an event sequence was started in late 1987 under the Shared Cost Action programme of the Commission of the European Communities. Teams from the following countries participated in the exercise: Belgium, Denmark, France, Germany, Italy, The Netherlands, Spain, Sweden, UK, and USA. The exercise ended in 1989.

The Event Sequence Reliability Benchmark Exercise was a logical continuation of a series of three previous exercises on system analysis, common-cause failure, and human factors. The exercise concerned an incident in the same plant as the one dealt with in the two previous exercises, the German Grohnde PWR nuclear power station. The initiating event was a loss of offsite power. The exercise involved the identification and analysis of all subsequent sequences that could develop during a period of 14 hours and lead to core melt-down. The analysis included both independent, common-cause, and human failure events.

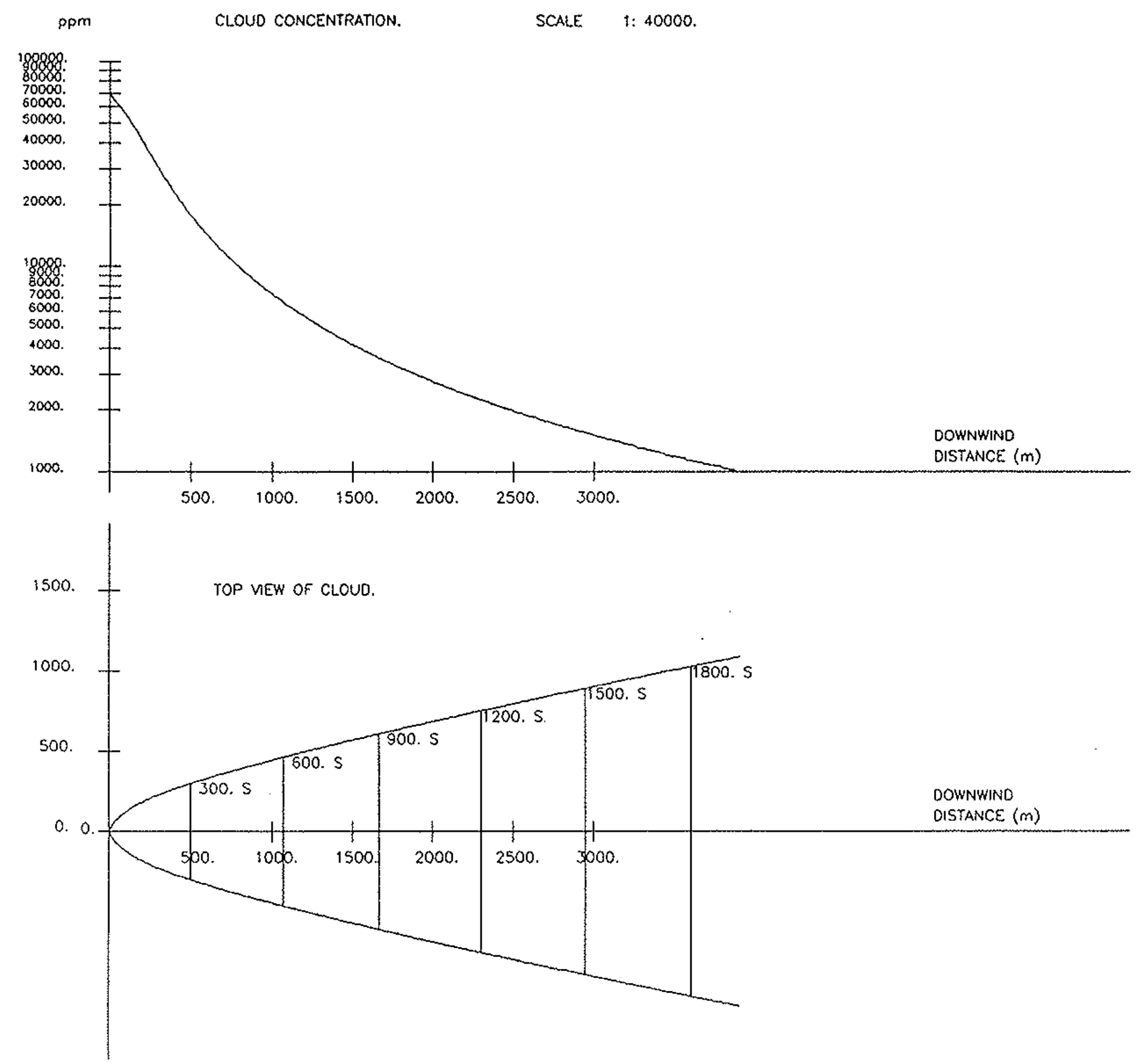


Figure 2.9. Horizontal contour of the heavy plume caused by discharge from a guillotine break of the vertical pipe between the pressurized storage tank and the valve VA; and the NH_3-concentration versus the down-wind distance. The position of the leading edge is indicated every 5 minutes.

Release rate: 40 kg/s. Wind velocity 2 m/s. Ambient temperature: 100C. Surface roughness: 0.01 m.

The first phase of the exercise was started in 1987 and was reported in 1988. In order to facilitate a more detailed comparison between team results, the analysis in phase two was restricted to sequences which involved success of the startup and shutdown system and failure of the demineralized water supply system. With one exception, the results of the different teams showed a factor of 15 total spread. This spread can be attributed primarily to differences in the estimates of common-cause and human failure events.

The experience of Risø's team was that probabilistic calculations, in which the individual events are independent, can lead to serious errors. Monte Carlo simulation by Risø's MOCARE program proved to be a very efficient and systematic tool for quantifying the resulting extremely complex event sequences, which include common-cause failures and negated events.

2.10. The Great Belt Fixed Link

The establishment of the Fixed Link over the Great Belt (Storebælt) is the largest single construction project ever carried out in Denmark. The Systems Analysis Department has taken part in studies of the Link, both from the points of view of energy and the environment and risk assessment.

The Risk Analysis Group has been involved in an overall risk analysis of the Fixed Link in collaboration with Cowiconsult Consulting Engineers and Planners A/S and Rowe Research Engineering Associates Inc. (USA.) The study was initiated in 1988 and addresses safety aspects common to several parts of the link. All aspects of risk are addressed with emphasis on the risk to individual users and society and the risk of disruption.

The Link will consist of three main parts:

- a railway tunnel from Sjælland to Sprogø,
- a road bridge from Sjælland to Sprogø, and
- a combined rail and road bridge from Sprogø to Fyn.

In 1989 the Risk Analysis Group contributed on two items:

- implementation of a safety management system, and
- operational risk analysis for the eastern bridge (Sjælland to Sprogø).

Operational risk analyses for the two other main projects of the Link have been performed earlier.

The objective of the safety management system, developed in collaboration with Technica (Norway), is to ensure a systematic approach to safety during design, construction, and operation. The system also aims to ensure that all recommendations and assumptions made to demonstrate compliance with stated safety objectives are valid throughout the lifetime of the Link.

A very important element of the system is the risk accounting system. The purpose of this system is to ensure that recommendations and assumptions from risk analysis and other safety related activities are followed-up in the project, both during design and operation. In the risk accounting forms, all entries are classified according to:

A: the need for risk reduction justified by risk assessment and comparison with risk acceptance criteria,
B: recommendations for risk reduction or risk control based on a qualitative evaluation, and
C: other safety-related comments.

Furthermore, an entry contains information on status, risk factor, reference document, and a number reflecting which part of the Link and what operational mode it relates to.

In collaboration with Cowiconsult an operational risk analysis was made for the eastern bridge. The analysis was based on an early stage of design. The Risk Analysis Group contributed by evaluating the collision risk from aircraft and the consequences of fire and explosion on the bridge. The main risk, viz. ship collision, has been analysed separately together with investigations on ship traffic and ship simulation by Cowiconsult and DMI (Danish Maritime Institute). Calculation of the probability of an aircraft colliding with the bridge is based on accident statistics and a geometrical target model.

The impact from an accidental release of liquid petroleum gas (LPG) or petrol from a roadtanker was analyzed. It should be noted, however, that on the basis of existing traffic patterns for LPG and petrol tankers, the likelihood that such vehicles will be found on the bridge at any time will be very small, resulting in a very low probability that such accidents will occur.

2.11. ESA/Water Management System

In collaboration with De Danske Sukkerfabrikker and Lyonnaise des Eaux (France) a prestudy concerning a water management system for long duration space missions was conducted for the European Space Agency (ESA).

The purpose of the system is to purify water from a number of sources for use as drinking, wash water, etc. The demands on such a system are extremely stringent: the quality of the purified water must be high, while the size and energy consumption of the system must be kept to a minimum with a maximum of reliability.

Technologies which have been considered include reverse osmosis, electrodeionization, H_2O_2/UV oxidation, vapour compression distillation, and sterilization.

At this early stage of the project where the specific technology to be used has not been chosen, a detailed reliability analysis could not be carried out. It is clear, however, that the system will consist of three parallel purification lines, and that reverse osmosis filtering will be used. Therefore the two investigations mentioned below were meaningful in order to carry out this stage of the design.

A logistic study of water flow and storage for the three purification lines was carried out. The primary goal was to guarantee a sufficient stock of pure water. The purification methods hold potential risks of contamination of the water with chemicals and microorganisms, so the study suggests an optimal configuration of the system with hold-up tanks at strategic points in the lines.

In order to test applicability of a preliminary ESA standard for hazards analysis, PSS-01-403 "Hazard Analysis Requirements and Methods", this standard method was applied to a single reverse osmosis filter unit.

The procedure is a formal and systematic way of identifying hazards, hazardous conditions, and undesirable events and their consequences. The identification is based on a generic checklist.

It was found that the method is very systematic, but should at no time be used beyond the actual level of design. A few formal improvements to the method have been suggested to ESA.

2.12. Physical Modelling of Torch Fires

Work on the project "Physical modelling of torch fires" has been continued. The project is part of the CEC research programme "Major Technological Hazards" and aims at obtaining reliable modelling techniques for heat transfer from an atmospheric diffusion flame to its surroundings and any engulfed objects. Several European research institutions besides Risø are involved in the project: TNO (Netherlands), UPM (Spain), ARS (Italy), and DMI (Denmark).

The modelling techniques to be developed are of two kinds: computer programs and scaling rules (in conjunction with wind tunnel experiments). The task of Risø is to carry out large-scale field experiments aimed at creating a set of reference data against which new methods of modelling can be tested.

During 1989 the work has concentrated on the following areas: 1)preparation of test-site for experiments, 2)design and manufacture of measuring equipment, 3)data-acquisition, 4)safety for personnel and equipment, 5)data-processing, in particular digital image processing of videotape, and 6)design of the experimental plan.

Preparation of the test site included the installation of systems for supplying electrical power, nitrogen, cooling water and transmission of signals. Following assembly, the burner was tested at maximum gasflow. The test was successful and indicated that the flame model used as a design basis gives a reasonable estimate of flame dimensions.

In addition to the flame measurements already planned, i.e. the temperature field within the flame, heat flux field around the flame and visual flame geometry, it has become possible to include infrared flame geometry. Both visual and infrared geometry will be recorded by video cameras. Ellipsoidal radiometers and a pyroelectrical radiometer have been chosen to detect the near and distant radiative heat flux fields respectively. For the most demanding measurements, namely, finding the temperature field within the flame, it was decided to use thermocouples mounted on a mast constructed to withstand the conditions inside the flame and be carried to another location despite its size, which covers all possible flame heights (7 m).

Apart from the video cameras, each sensor of the measuring equipment produces a voltage which will be sampled automatically at an appropiate frequency (related to the time-constant of the sensor), transformed to the value of the corresponding physical quantity, and stored on a diskette. This PC-based system of data acquisition has been programmed.

As the current experiments involve large flows of gas (up to 1000 Nm^3/h), dangers such as flames on leaks, flash fires. UVCEs, etc. have to be considered and excluded as far as possible by system design and operating procedures. Furthermore, efficient emergency procedures are needed in case accidents occur in spite of these measures. On the basis of a risk analysis of the test site and other considerations, additions to the original system design and procedures have been worked out.

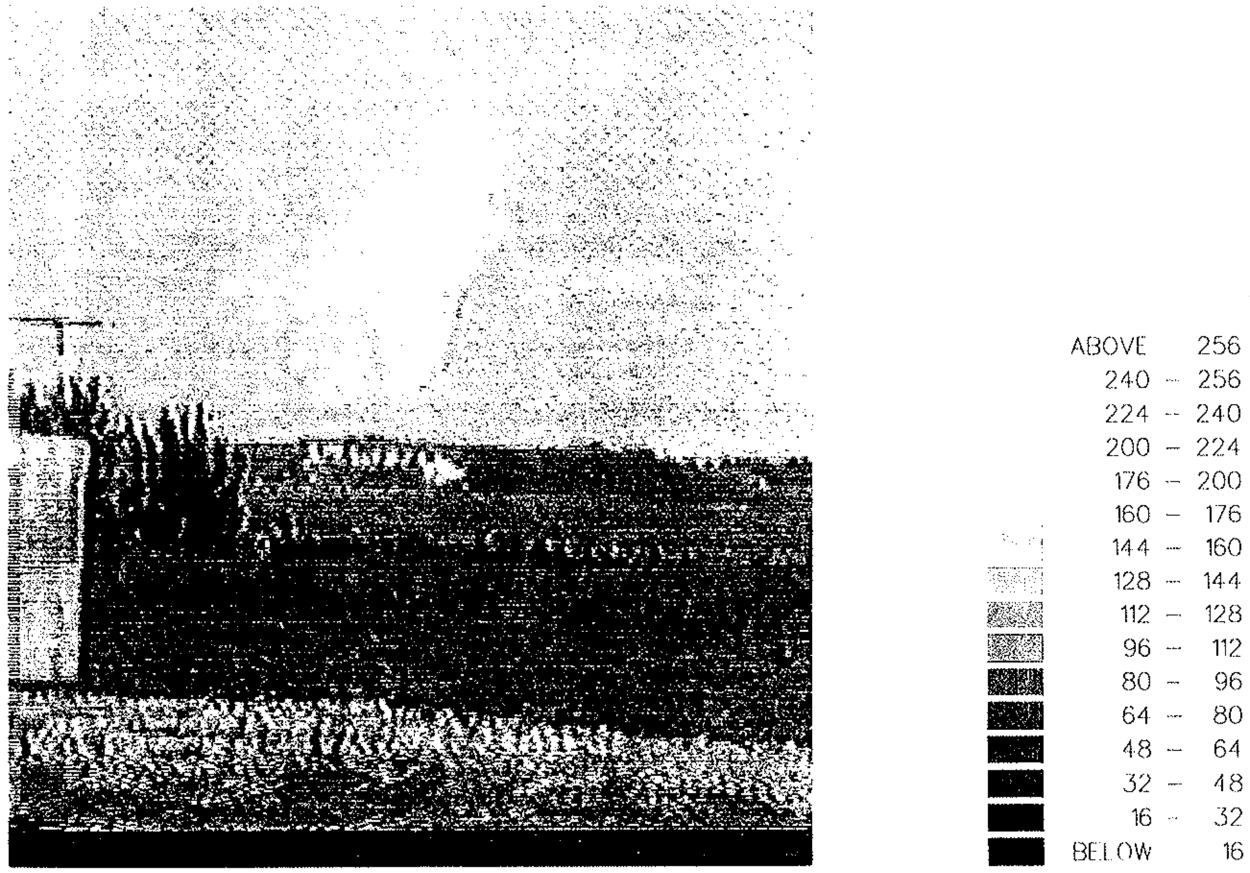
Microsecond photographs of a flame show a highly stochastic geometry. The basis of 1-dimensional flame models, however, is a stationary emitting surface, so a way must be found to average the pictures recorded on videotape. It is found to be digital image processing (DIP): The composite videosignal from a videocassette recorder loaded with a flame video is transferred to an RGB (red/green/blue) form in a decoder board

inserted in a PC. An analog-to-digital converter board in the same PC receives the RGB signal and digitizes each "picture" (two constructive fields) and then passes the result to a hard disk. Via a network, the picture file is transferred to the much more powerful VAX 8700 computer where the picture analysis program is resident. Also resident is the UNIRAS graphics system, which allows the plotting of picture files. One example of such a plot is shown in Fig. 2.10. The picture analysis program has not yet been fully tested, but the tests performed so far are satisfactory.

Large-scale experiments are rather costly, and this means that each condition to be tested has to be chosen carefully. An experimental plan has been set up using the "central composite design" method.

It is planned that all the experiments will be performed during 1990.

Figure 2.10. Gas burner with flame. Plot of 2 digitized, consecutive fields on videotape. Legend shows classes of light intensities.



3. Environmental Modelling

The Environmental Modelling Group (EMG) was established in the Systems Analysis Department in 1988. The overall aim of the group's work is to develop and apply models which can contribute to building up a complete picture of how pollution affects the environment. Such knowledge of the connection between the activities of society and their environmental consequences can facilitate cost-effective measures to combat pollution.

In more specific terms the activity of the group has been centred on further development and use of the ECCES model which has been developed over the past seven years under the Energy Research Programme of the Ministry of Energy. Work in 1989 has been primarily concerned with the application of the model to forest soils.

A Ph.D. project concerned with qualitative biological changes in lakes was initiated in the beginning of the year in collaboration with the Royal Danish School of Pharmacy.

3.1. Application of the Soil Chemistry Model to Forest Soils

During 1988 the ECCES model was extended with a forest module. The module simulates in rather simple terms the changes which occur in the composition of rainwater when it comes into contact with the forest canopy and with decaying litter on the forest floor. After this extension the model is then able to simulate the impact of air pollution on both agricultural soils and forest soils.

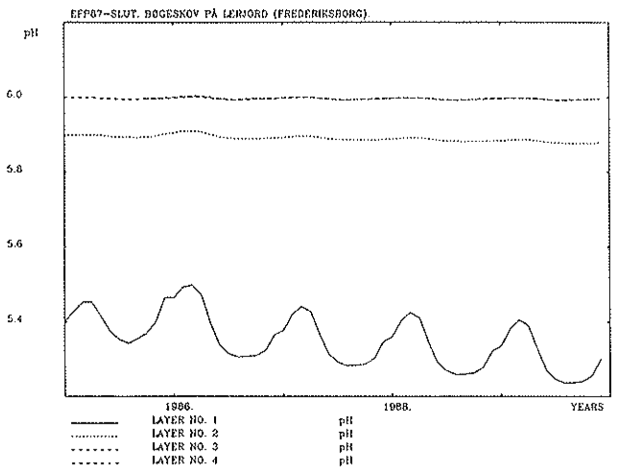
In parallel with the model development, results from simulations have been verified against data from laboratory experiments in which soil samples have been treated with synthetic rainwater. These experiments indicate that the basic assumptions in the model are reasonable, but one could raise some objections to the experiments:

- The experiments were carried out with a high water to soil ratio; although it is no problem for the model to deal with this situation, it is not as realistic as one could wish.
- The experiments give no information about the assumption that equilibrium exists between the ions in the soil water and the ions on the ion exchanger.

The work was carried out under the 1985 energy research programme of the Danish Ministry of Energy and was reported in 1989 (Christiansen et al. 1989). Work on the model was continued under the 1987 energy programme of the Danish Ministry. This project was an extension of an ongoing project carried out in collaboration between the Danish Forest Experiment Station and the National Environmental Research Institute (Air Pollution Laboratory), in which the ion flux in forest systems was studied through measurements of dry and wet deposition, litterfall and chemical changes in the soil. The purpose of the project was twofold, a) to collect additional data for forest systems, required for the simulations, and b) using these data in connection with the previously obtained data as input to the ECCES model in order to test the model on a real ecosystem. In this way the project was aimed at providing some experience in applying the model and an opportunity to verify the results, as the soil at the experimental site is in a pH-range in which the model can be expected to give reliable results. If it had been a sandy soil with a low pH, it would still be possible to use the model, but the results would have been somewhat uncertain, because the model does not include all the relevant buffering mechanisms for low pH values.

By the end of 1989 a number of simulations had been run, but the comparison of results with experimental data was not completed, mainly because the last soil samples had not yet been analysed. Figure 3.1 shows a plot of pH in the soil

Figure 3.1. Result of a simulation over 5 years showing the development of pH in the 4 layers.



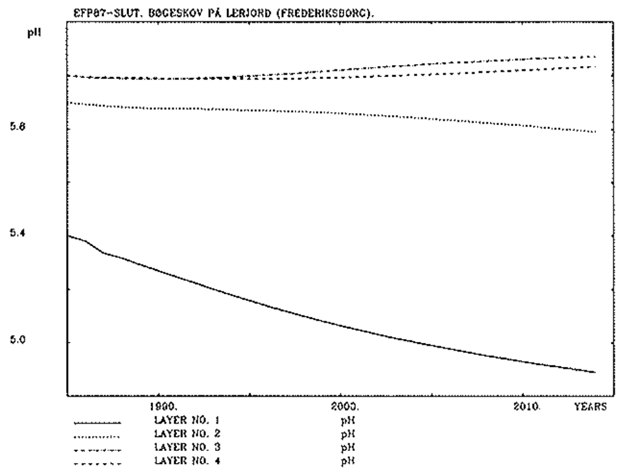


Figure 3.2. Result of a simulation over 30 years showing the development of pH in the 4 layers.

layers from a five-year simulation. The soil layers are numbered from the top, with a depth of 25 cm for the three upper layers and 35 cm for the lowest. It is seen that the uppermost layer has a significant variation in pH, while it is rather constant in the other layers. This is a result of the relatively high buffering capacity of the simulated clay-soil.

The pH-development in a 30-year simulation is shown in Figure 3.2. In this simulation as well a significant effect is seen only in the uppermost layer. In the two lower layers there is even a slight increase in the pH-level. These findings are not so surprising, as the simulated soil is a clayey type and thus not expected to be very sensitive to acid deposition. Furthermore, the experimental site in northern Zealand is situated in an area where the acid deposition cannot be considered to be particularly large.

It was hoped that the experimental data could be used to validate the calculations for microelements. Unfortunately, the microelement concentrations have been shown to be so low that it is impossible to get reliable data from analyses of water samples. Nevertheless, the data can be used to set an upper limit for the concentrations, and thereby to judge if the results from the model lie in a reasonable range.

The final report on the project will be issued early in 1990.

3.2. Heavy Metals in Soils

Due to the toxicity of heavy metals it is important to be familiar with their distribution in the ecological system.

The main aim of the ECCES model is to predict changes in soil chemistry induced by acid rain. Therefore, we have concentrated our efforts on calculations to determine the dependence of chemical equilibrium in the soil upon pH. In addition the model also contains facilities for calculating the concentration of ions in agricultural crops.

The crop uptake calculations depend upon the water uptake (W_{upt}) of the crop, the concentration of the specified ion in the soil water (C_{ion}), upon a discrimination factor (F):

$$Ion_{upt} = W_{upt} * C_{ion} * F$$

If the discrimination factor is larger than the ion is considered to be taken up actively. If F equals one the ion is taken up by passive diffusion, and for F between one and zero the ion uptake is discriminated against.

Two fundamentally different calculation methods exist for determining the ion concentration in soil water. One of these is incorporated in the ECCES model version 3.3 and the other, based upon empirical data, is incorporated in ECCES version 3.4.

The first depends almost exclusively on the variable and permanent cation exchange capacities. This implies a dependence on pH as the variable cation exchange capacity varies with pH, (hence the name). The latter depends on pH, the total cation exchange capacity and the content of reactive manganese oxides, organic carbon, clay and iron oxides in the soil.

These two versions of the ECCES model have been tested against each other at varying soil water concentrations, pH values and on two different soil types. Figure 3.3. shows the relationship between the amount of cadmium adsorbed on the soil and the amount in solution at a fixed pH-value. Figure 3.4. shows the relationship between pH and the amount of adsorbed cadmium at fixed soil solution concentrations.

These calculations have been discussed by Christiansen (1989) where it is concluded that the ECCES model version 3.4 gives the best picture with carying pH as well as soil water concentrations.

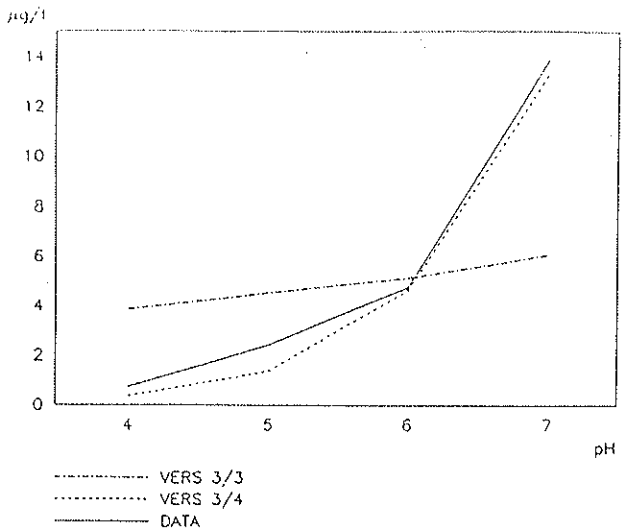


Figure 3.3. Relationship between Cd in soil and in solution at fixed pH.

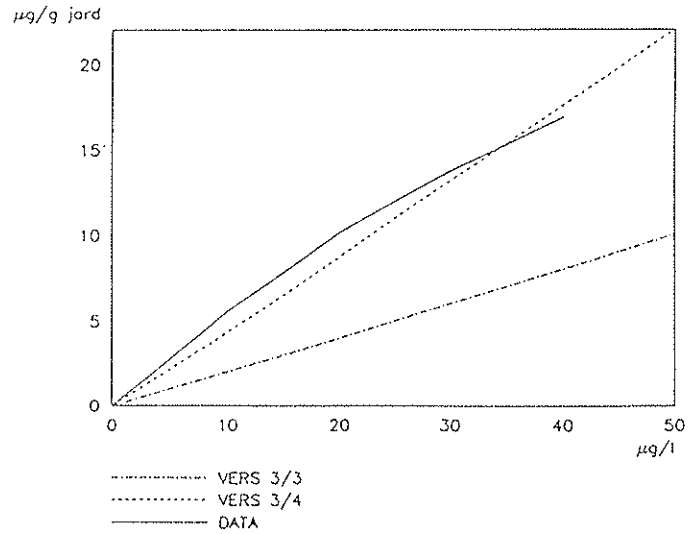


Figure 3.4. Relationship between pH and adsorbed Cd at fixed soil solution concentrations.

3.3. Structural Dynamical Modelling and Exergy of Aquatic Modelling

Ph.D. project has been started to analyse the impact of production on aquatic ecosystems. The work is being carried out in close collaboration with the National Environmental Research Institute, where a database registering the conditions in Danish lakes is being developed.

A large number of Danish lakes have been observed to show dramatic changes with regard to species composition of the micro-algal society and the trophic structure of the ecosystem during increasing eutrophication. The changes into a new structure appear to be stable, and it is often difficult to "trigger" a return to previous conditions during divertion or unloading processes.

To reveal the cause of the observed changes and as a helping tool to decide what to do to establish former conditions in the lakes, a model has been developed to simulate structural-dynamical changes in Danish shallow lakes.

The first model was constructed to contain 9 state variables representing 6 types of phytoplankton and 2 types of zooplankton and the pool of soluble phosphorus. Model simulations were run at several levels of eutrophication, i.e. over a wide spectrum of phosporus input to the lake. At the same time several other factors were varied, especially the different phytoplankton losses to analyze their influence on the development of the ecosystem structure while running the system into a steady state.

Simulations showed that sedimentation and grazing losses have a great impact on the composition of the phytoplankton society. The recirculation of phosphorus within the sediments is also considered an important factor in producing the level of eutrophication of the lake.

The model has been validated qualitatively, i.e. it is able to simulate changes in the species composition and trophic structure of the ecosystem at different eutrophication levels. At the moment, the model is also being validated quantitatively, i.e. tested against data from case studies on 4 Danish lakes. The first runs indicate, however, that more types of algae are needed and three more types are being integrated to validate the cases properly. Also, an improvement of the zooplankton submodel is needed, and these corrections to the model are being carried out.

During recent decades several factors have been proposed as optimizing or goal functions for the development of biological systems such as ascendency, network flow, and exergy. An attempt to identify such a goal function is applied in the study, and since exergy has previously shown to work well as an optimizing function in simple models, the theory was chosen to be tested against this highly complex model. It has been shown that during the development of an ecosystem the type of algae that replaces another always represents a state of higher exergy. Thus the theory of maximum exergy can also be seen as a thermodynamic expression of the Darwinian principle of natural selection.

4. Energy Systems Analysis

The activities of the Energy Systems Group (ESG) involve the development of energy-economy models, energy and environmental planning and technical-economic assessments of energy systems and technologies.

ESG participates in overall Danish energy planning, including the process of establishing the framework for this planning. New models are constructed and existing models used for calculating future energy requirements and emissions based on different scenarios.

The environmental aspects of energy conversion and use have become an increasingly important part of energy planning in recent years, reflected in the work of the Energy Systems Group. This has been particularly evident during 1989 in which work connected with the Brundtland report comprised a major part. Many of the other activities of the group also have an environmental connection, in most cases with respect to the quantification and localisation of emissions from energy conversion.

4.1. European Commission Models for Energy and Environment

For a number of years the Energy Systems Group has been responsible for the Danish implementation of models developed within the research programme for rational energy use and systems analysis of the Commission of the European Communities. The main tasks carried out in 1989 were the documentation of work that was done during the 3rd CEC energy research programme ending 1988. The work dealt with three models: The macrosectoral model HERMES, energy flow optimisation model (EFOM), and simulation model DESS.

While macroeconomic models are used for forecasting the demand for useful energy or energy demand carriers, the supply side is modelled using a network description of the energy system in which the demand for useful energy is linked to the energy requirements by a number of energy conversion, transport, and distribution technologies.

4.1.1. The Macro-Sectoral Model HERMES

HERMES is an econometric medium-term model for determining economic development with special emphasis on energy-economy interactions. The objective of developing the model has been to generate a national model for each of the EC countries, of structure similar to the others, and interlink all of the models to create a multinational one. The structure of a typical national HERMES model, namely the Danish one, is illustrated in Fig. 4.1.

In 1989 work on the Danish national model concentrated on its documentation and updating. Details of the present version of the HERMES model are given in the report "The HERMES Model for Denmark" (Andersen 1989) which besides describing the structure, specifications, and predictions of the model includes a simulation over the past as well as a few multiplicator analyses performed using the unlinked national model. The simulation experiment shows that at the aggregate level the model is able to trace past developments in a fairly acceptable way. However, at the disaggregated level additional work on alternative specifications and reestimations have to be performed in order to obtain reasonable results, especially concerning the energy part of the model.

Updating the model is a continuous process comprising updating the data, making new estimates and revising minor parts of the model. In 1989 work in this area was concentrated on updating the disaggregated data to include those of 1985. At the aggregated level the data is updated to include the 1987 figures.

4.1.2. The Energy Flow Optimisation (EFOM) Model

The EFOM-model is the supply part of the CEC energy model complex, which has been used since the 70s. An extension of the model that includes emissions of pollutants as well as emission abatement techniques was developed as part of the project "Optimal Control Strategies for Reducing Emissions from Energy Production and Energy Use on a European Level". The results of this project concerning SO_2 and NO_x abatement

FIG.1 A FLOW CHART OF THE UNLINKED DANISH MODEL

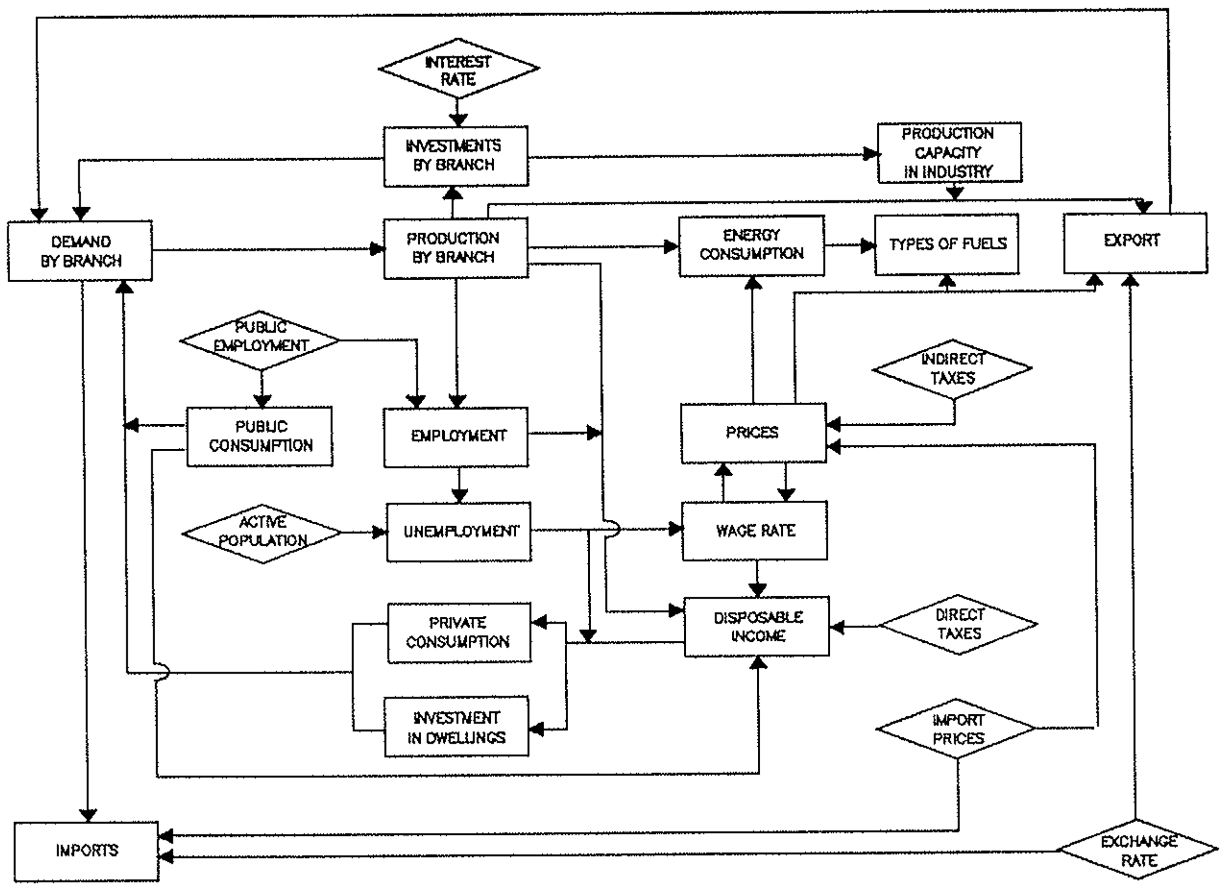


Figure 4.1. The structure of the HERMES model for Denmark.

strategies were published by the Commission in 1989, including reports from each member country.

The energy supply system is described as a network of energy conversion and transport facilities. For each scenario a linear programming problem is set up and solved in order to disclose an optimal solution for the sequence of investment in energy conversion and end-use technologies as well as emission abatement measures.

The EFOM-model has been implemented on the Digital VAX 8700 computer in cooperation with the Risø Computer Section. The optimisation part of this model system must be done by a commercial linear programming solver. The LINPROG linear programming solver developed by the Risø Computer Section has been used for the Danish implementation of EFOM.

4.1.3 The Detailed Energy System Simulation (DESS) Model

The DESS-model was implemented for Denmark, Germany and Italy as part of the Risø contribution to the 3rd CEC energy research programme. This work is documented in the reports "Simulation of the Italian Energy System with the DESS-Model" (Halsnæs and Sørensen 1989), which describes the space heating and power generating sectors, and the final report "The DESS Model: A Detailed Energy System Simulation Model for the EC Countries" (Grohnheit 1989b), in which the work is summarised, and the fields of application for the DESS and EFOM models are discussed.

As in the EFOM-model the energy system is described by a network which converts the energy demand to primary energy necessary for optimisation software. Fairly simple calculations are made to eventually produce a sequential simulation of the energy system. The system may be optimised outside the model by intuition or trial and error.

The applications of the DESS-model are summarised as follows:

- national database and simulation model for the energy system,
- multinational database and simulation model for the energy system,
- database and preprocessor for optimisation models, e.g. EFOM, and
- sectoral model, in particular for a power system with CHP.

At present the DESS software package is available for Digital VAX and IBM mainframe computers.

4.2. Simulation Model for the Production and Storage of Electricity and Heat

The utilization of renewable energy resources has a high priority in Danish energy planning. Many of the systems which use these resources will be built as collective plants producing electricity and heat for district heating systems in smaller towns. There is a tendency for the systems to become increasingly complex, including technologies using several different energy resources.

To be able to test various operating strategies for such complex systems, a simulation model has been developed and improved over the past few years. The most recent extensions of the model including modules for simulating heat and electricity storages have been financed by the Ministry of Energy and the Nordic Council of Ministers.

The model is very flexible. Not only are technical and demand data given by the user, but also the structure of the energy system and the operating strategy are specified, i.e. all information is given exogenously in a simple user-friendly way.

From data on various technologies, the structure of the energy system, the operation strategy, time series for energy consumption (heat and electricity) and meteorological data (insolation, wind, ambient temperature), and various economic parameters, the model simulates the operation of the system on an hour-by-hour basis.

By using this model it is possible from a technical and economic point of view to evaluate a complex energy production facility that includes several energy resources and conversion units. The model could be used both at the planning stage (i.e. before construction of the facility) and at a later stage when an optimum operating strategy is sought.

4.3. Technical-Economic Models for Offshore Oil and Gas Activities

On the basis of earlier work, a report on hydrocarbon and corporate taxation in connection with preliminary surveys, exploration, and recovery of oil and gas in Denmark has been prepared. The report also deals with royalty and transport charges for hydrocarbons from the fields in the North Sea to the refinery.

The modelling activities in this field during the year have been concentrated on a computer system called MECCA, which contains a cash-flow model for offshore activities, including submodels for hydrocarbon and corporate taxation. In 1989 the work on this system consisted of error-tracking and correction.

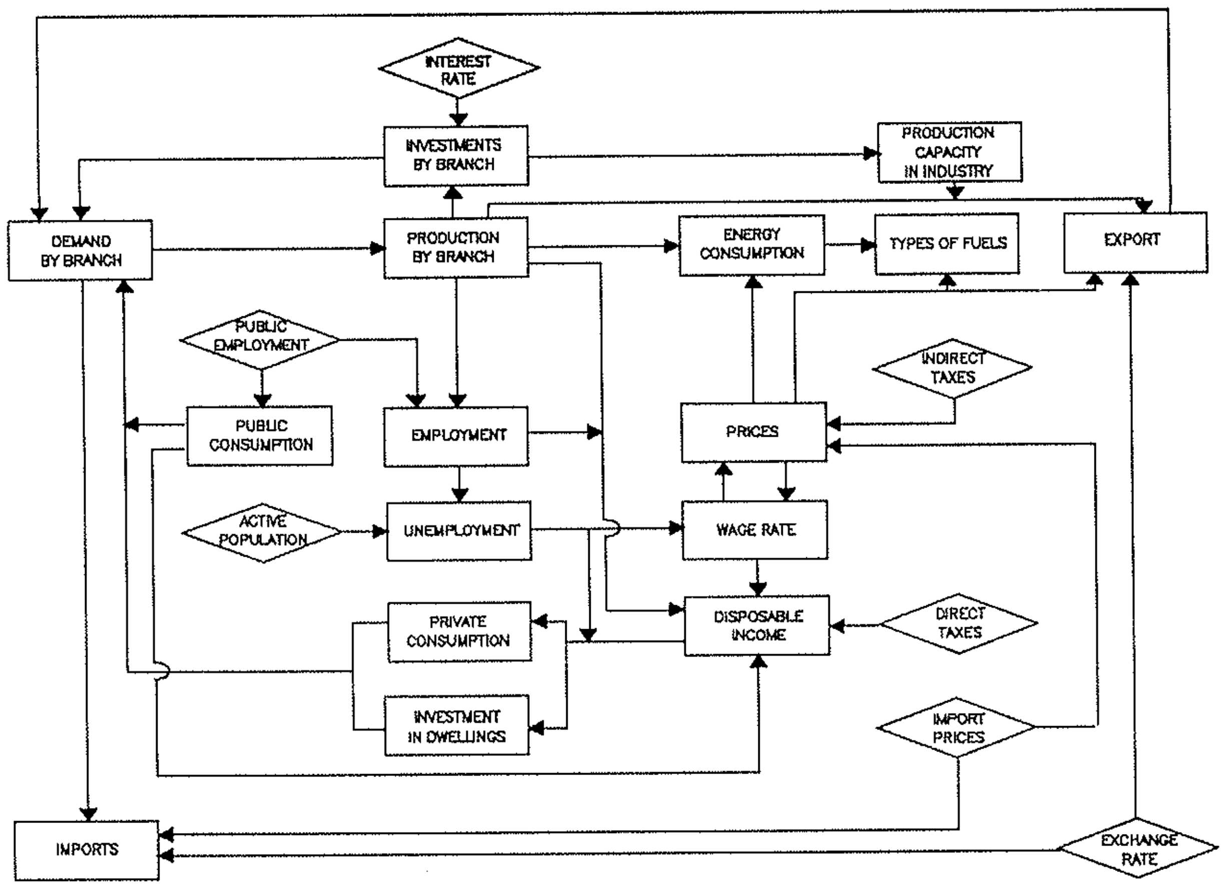
4.4. The Danish Brundtland Energy Plan

At the beginning of 1989 the Danish Ministry of Energy initiated work on the Danish Brundtland Energy Plan. The plan will be completed early in 1990 and submitted to the Danish Parliament shortly after.

The Brundtland Energy Plan was naturally inspired by the report of the World Commission on Environment and Development: Our Common Future (the Brundtland Report), which deals with the problems of how to achieve sustainable development. At the end of 1988 the Danish government launched a catalogue of ideas aimed at working towards sustainable development. The effort on the Brundtland Energy Plan centres on how these ideas can be applied to actual problems in energy and environment.

Five working groups were set up to carry out the work and these groups dealt with the following topics:

FIG.1 A FLOW CHART OF THE UNLINKED DANISH MODEL



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- sectoral model, in particular for a power system with CHP.

At present the DESS software package is available for Digital VAX and IBM mainframe computers.

4.2. Simulation Model for the Production and Storage of Electricity and Heat

The utilization of renewable energy resources has a high priority in Danish energy planning. Many of the systems which use these resources will be built as collective plants producing electricity and heat for district heating systems in smaller towns. There is a tendency for the systems to become increasingly complex, including technologies using several different energy resources.

To be able to test various operating strategies for such complex systems, a simulation model has been developed and improved over the past few years. The most recent extensions of the model including modules for simulating heat and electricity storages have been financed by the Ministry of Energy and the Nordic Council of Ministers.

The model is very flexible. Not only are technical and demand data given by the user, but also the structure of the energy system and the operating strategy are specified, i.e. all information is given exogenously in a simple user-friendly way.

From data on various technologies, the structure of the energy system, the operation strategy, time series for energy consumption (heat and electricity) and meteorological data (insolation, wind, ambient temperature), and various economic parameters, the model simulates the operation of the system on an hour-by-hour basis.

By using this model it is possible from a technical and economic point of view to evaluate a complex energy production facility that includes several energy resources and conversion units. The model could be used both at the planning stage (i.e. before construction of the facility) and at a later stage when an optimum operating strategy is sought.

4.3. Technical-Economic Models for Offshore Oil and Gas Activities

On the basis of earlier work, a report on hydrocarbon and corporate taxation in connection with preliminary surveys, exploration, and recovery of oil and gas in Denmark has been prepared. The report also deals with royalty and transport charges for hydrocarbons from the fields in the North Sea to the refinery.

The modelling activities in this field during the year have been concentrated on a computer system called MECCA, which contains a cash-flow model for offshore activities, including sub-models for hydrocarbon and corporate taxation. In 1989 the work on this system consisted of error-tracking and correction.

4.4. The Danish Brundtland Energy Plan

At the beginning of 1989 the Danish Ministry of Energy initiated work on the Danish Brundtland Energy Plan. The plan will be completed early in 1990 and submitted to the Danish Parliament shortly after.

The Brundtland Energy Plan was naturally inspired by the report of the World Commission on Environment and Development: Our Common Future (the Brundtland Report), which deals with the problems of how to achieve sustainable development. At the end of 1988 the Danish government launched a catalogue of ideas aimed at working towards sustainable development. The effort on the Brundtland Energy Plan centres on how these ideas can be applied to actual problems in energy and environment.

Five working groups were set up to carry out the work and these groups dealt with the following topics:

- space heating and electrical appliances,
- industrial energy consumption,
- technologies for producing power and heat,
- biomass and local resources, and
- energy and environmental systems.

The first four groups were given the specific task of collecting data on technologies, potentials for energy savings, etc., and how these could develop with time. The final group was responsible for coordinating data collection and applying these data in different scenarios set up by the newly constructed Brundtland Scenario Model.

The Energy Systems Group participated intensively in these working groups, and chaired the groups concerned with industrial energy consumption and energy systems. With regard to the group concerned with evaluating technologies for power and heat, ESG shared the work with Danish utilities, and took part as a member of the group on space heating and electrical appliances. Each of the working groups submitted comprehensive reports on their respective areas to contribute to the final report on the Brundtland Energy Plan.

Besides having the chairmanship of the systems group, ESG developed a scenario model to be used in the systems evaluation. A brief review of the main characteristics of the model will be given below.

The Brundtland Energy Plan has a long time horizon, and the calculational tools that are to be developed have to deal with energy, the environment, and the national economy in an integrated way:

The main characteristics of the Brundtland Scenario Model can be summed up as follows:
- long-term simulation model, looking ahead to year 2030,
- split into different sectors of demand and supply, although these sectors are integrated to give a comprehensive tool,
- energy demand and the development of energy production capacity are driven from the demand side,
- possible to choose different savings options for insulation, appliances, and processes,
- possible to choose from a large number of conversion technologies, ranging from individual oil burners to wind turbines and large-scale coal-gasification plants.

The main results of the model are gross energy consumption split into different fuels, emissions of CO_2, SO_2 and NO_x, and, finally, the economic consequences of the chosen system set-up.

The structure of the model is illustrated in Figure 4.2.

As can be seen in the figure, the model is split into different modules, starting with one for society at large: demography and economic development at the macro level. It is then split into industries, energy prices, etc.

On the basis of these assumptions, the model proceeds to the energy demand side, divided into three modules: space heating and electrical appliances, industrial energy consumption, and transport.

The first two modules distinguish between dwellings and buildings used for public and private services, while household electrical appliances and appliances used in services are covered in a specific submodule. Space heating is treated according to:
- building stock and development in building area,
- the structural development in the building stock (single-family and multi-family dwellings, service buildings, etc.),
- the geographical development in the building stock (due to different possibilities for heating supply),
- insulation standards for different building types and years of construction
- options for individual or collective energy supply, and
- a range of individual supply technologies (oil and natural gas burners, heat pumps, electrical resistance heating, solar collectors for domestic hot water, etc.).

The module calculates net heating energy needs and final energy consumption for space heating.

Appliances are treated according to:
- the stock and development in the number of appliances,
- possibilities for improved efficiency, and
- development of the service sector at large, the use of service appliances, and savings possibilities.

Industrial energy consumption is treated by:
- splitting into main energy-intensive branches,
- developing production and a production mix,
- savings possibilities, technology and fuel switching, and

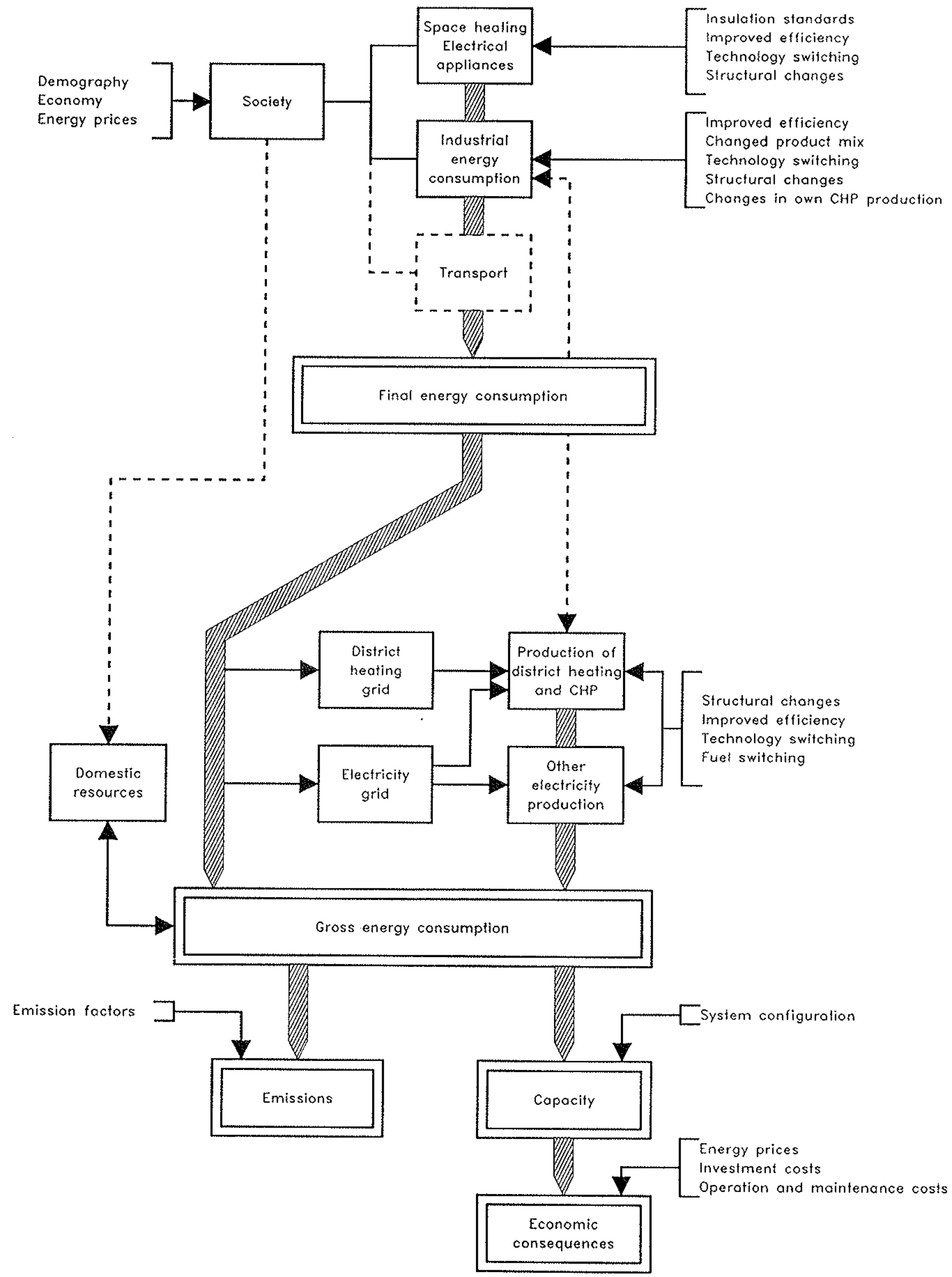


Figure 4.2. Structure of Brundtland Scenario Model.

- own production of combined heat and power (CHP).

With regard to CHP this is linked to the supply module of the model.

Energy consumption for transport is not treated explicitly in the model. The existing module may be regarded as a dummy. The main reason for this is that transport is the responsibility of the Ministry of Transportation rather than the Ministry of Energy. In due course the results of the Brundtland work carried out in the Ministry of Transportation will however be included in the model.

The final energy consumption is calculated by summing the results from the demand modules. The electricity and district heating demands are converted to gross energy in the supply models of the model: modules for district heating and electricity grid, for production of district heating/CHP, and other electricity production. These modules incorporate a large number of existing and future technologies characterized by a number of technical data such as overall efficiency, technology-specific emission factors, production relations between heat and power, system-specific data as utilization time, etc. The model allows a free choice between a large range of technologies from traditional power plants to fuel cells and small-scale biomass CHP-plants.

Gross energy consumption is calculated by considering the requirements for energy conversion and this is compared with the available domestic resources. Using emission factors for fuel and technology-specific emissions, the total emissions of CO_2, SO_2, and NO_x are calculated.

Finally, for the chosen system configuration the model calculates the total installed capacity (split into different types of plants and technologies) and, using data for energy prices, investments and operation and maintenance costs, the total annual economic costs of the chosen system are calculated.

As mentioned above, the model is an integrated tool for the whole energy system and substantial changes can be introduced in one module without generating the need for changes elsewhere in the model. For example the demand for energy can be halved without changing the supply system and the model can still generate reasonable results. In the case of diminishing energy demand it still might be relevant to change the supply structure.

At the end of 1989 a preliminary report was prepared for the Ministry of Energy. Included in this report were a range of partial model analyses concerning energy savings and different technology configurations. The main results of these partial analyses were:

- The majority of electricity savings and a large part of space heating savings considered seem to be economically feasible.
- The ongoing use of waste heat from power plants has to be encouraged and developed, especially from small-scale CHP-plants, so that as large a part of the heat demand as possible is covered by surplus heat.
- Because of the expected decrease in the overall demand for heat supplies it is highly relevant to introduce technologies with a higher electricity-to-heat ratio (e.g. fuel cells) than existing today.
- Increased use of domestic resources (e.g. biomass) and to a certain extent renewable energy technologies (e.g. wind turbines) is economically feasible.

To achieve the targets of the Brundtland report, however, partial actions such as energy savings are not enough. To reduce the emission of CO_2 by 50% it is necessary to use all relevant options: energy savings, enhanced use of CHP, introduction of high-efficiency conversion technologies and abatement technologies, increased use of biomass and renewable energy technologies. The preliminary results indicate that if all of these options are employed then it may be possible to obtain a 50% reduction in CO_2 emission without substantial increases in annual economic costs of the system.

4.5. The Economic Interdependence between the Industrial and Developing Countries - the Channels of Transmission

Within the field of international economics there is general agreement concerning the increasing interdependence between the industrial countries and less developed countries (LDC's). The picture of the mechanism through which this transmission operates is rather poorly understood. In particular, there is a lack of knowledge with regard to the magnitudes or importance of the different channels of interaction. A lack of reliable relevant data for the developing countries has, until recently, been a major impediment to empirical modelling of their economies. Therefore, most of the work until now has been within a single equation estimation approach (partial equilibrium studies of individual linkages) or simulation modelling.

The aim of the Ph.D. project based on this work is to clarify the theoretical background to international economic transmission, with emphasis on theories directly connected to the LDC's, and to quantify the channels of transmission within the framework of general equilibrium theory.

The following main channels of economic interdependence are identified in the thesis.

The economic performance of the industrial countries affects the developing countries either by real transmission through foreign trade, or by financial transmission through capital markets. An increased rate of growth in the industrial countries will raise developing countries' exports to industrial countries, and thereby increase income and employment in the LDC's in the short run and the relative size of the export sector and growth rates in the longer run. The strength of this channel varies of course, depending on the types and volumes of exports and the impact on relative prices. Changes in the terms of trade will also affect ability of the LDC's to earn foreign exchange and serve their external debt.

An increase in inflation rates in the industrial economies will raise prices in the developing countries, and thereby increase the purchasing power generated by their exports. An increase in the degree of protectionism on the part of the industrial countries will lower the developing countries' exports volumes, and indeed will seriously affect their economies, since some 65% of their exports are to the industrial world (based on 1987 figures).

Fluctuations in world energy prices affected the economics of the oil-exporting developing countries very strongly in the period 1970-1974. The average annual changes of the purchasing power of their exports were close to 60%; at the same time the changes in purchasing power of the exports of the non-oil exporting developing countries and industrial countries' were 4.6% and 6.2%, respectively. Since 1981 the purchasing power of the oil-exporting developing countries has declined by approximately 12% per year, while during this period the two other groups have experienced positive average changes.

The importance of capital movements from the industrial to the developing countries has been growing in recent years. Here, exchange rates and interest rates serve as the main factors governing these flows. The access of a country to credit and the extent of investment in it are also important factors.

The reverse interactions – the effects on the industrial world of the economic performance of the developing countries – are often neglected. With about 20% of the exports of industrial countries going to developing countries, a lowered growth rate in the developing world will lower the demand for industrial exports and have an adverse effect on the growth of the industrial world.

The empirical part of the thesis comprises an introduction to the OECD world model INTERLINK and three other international macromodels. In the study there is a simulation of various economic shocks within INTERLINK, an interpretation of the results, and a comparison with simulation results from the other models.

The model simulation describes the significant influence of changes in economic policy in the industrial countries on economic prospects in the developing countries. In particular, higher interest rates will worsen the economic conditions in the developing countries. Changes in the price of oil have considerable consequences for the OPEC countries, while the consequences for the other developing countries and OECD members are less significant than have been expressed in some previous empirical studies. Feedback effects, i.e. reverse interdependence, are shown to be significant, but less than indicated in the beginning of the study. The empirical results support the general agreement among economists that the foreign debt of developing countries is the main hurdle for economic growth and increased welfare in the developing world.

4.6. Evaluation of Renewable Energy Technology Projects

In 1989 the Danish Council of Technology initiated an evaluation of the projects in the area of renewable energy which they had supported in the period 1980-88.

The Council appointed an evaluation group which will publish their conclusions in 1990.

The evaluation is based on three reports which have been prepared jointly by Risø and the University of Roskilde.

The purpose of the evaluation was to describe the impact of each supported project on the development of renewable energy in Denmark.

The first report (mainly made by Risø) describes the technological and economical development in the main areas of renewable energy in the period. All 321 projects, whose support came to a total of DKK 123 million, were investigated by published reports, interviews, case studies, and documents in the Council's archives. The support breakdown in the main areas were:

Area	number of projects	DKK million
Wind	103	35
Straw and wood	19	9
Biogas	74	36
Active solar heating	75	24
Passive solar heating	25	8
Solar cells	4	3
Wave and small hydro	5	3
Renewable energy in large cities	16	5
Total	321	123

Additional projects in the fields of planning, information, and education were described in the second report (prepared by Roskilde University). The total support for these projects amounted to DKK 157 million during the period. The second report also describes the effects in the industrial sectors involved.

The third report (prepared by Risø) describes the effect of renewable technologies on specific aspects of the Danish economy: export, import substitution, employment, etc.

The main conclusion of the evaluation is that the support has had a substantial impact on the development in the area of renewable energy during the period in question. The administration by the Council can be characterized as flexible and ready to support new and unproven technologies.

4.7. Integrated Energy and Environmental Planning

A group consisting of participants from COWIconsult, the Technical University of Denmark, the Danish Energy Agency, and Risø has been working on a project aimed at studying and modelling the coupling between energy production and use and the resulting environmental impacts. The model is to be used in a way which may suggest coordinated solutions to environmental problems caused by airborne emissions of selected pollutants: SO_2, NO_x, CO_2, polyaromatic hydrocarbons (PAH), and as an example of a significant heavy metal, Cd.

The island of Bornholm has been used as the region to be studied in this project but it is intended that the methods and tools being developed will be relevant for application in other regions.

ESG has been mainly involved in the following areas of work:

- Elaborating of the present level of energy consumption for space heating and the resulting emissions. This work comprised an expansion of a tool which sorts and handles data stored in the Central Building Registry in order to compute the fuel used and the resulting emissions.
- Establishing a set of specific emissions for PAH and Cd which gives the dependence of the emissions on the fuel type and the combustion method.

Preliminary results of the project have been presented in an interim report and at the Risø International Conference on Environmental Models in May 1989.

4.8. Methods and Models in Nordic Energy and Environmental Planning

A critical review has been made of existing models used for energy and environmental planning in the Nordic countries in order to investigate the need for methodological improvements in integrated energy and environmental models. The

project is financed by the Nordic Council of Ministers.

For the purposes of the study, integrated energy and environmental models are defined as those which treat energy system optimization criteria such as security of energy supply, cost minimization of energy conversion, etc. as well as criteria regarding environmental consequences of the energy system. In practice it is very difficult to treat these in a single model because the environmental consequences of the energy system can be described only if energy system models, dispersion models, and ecological models are combined.

The total "chain" of processes from energy demand and conversion to final environmental consequences is shown in Figure 4.3. On the basis of the description of links between the energy system and environmental consequences shown in the figure, a number of detailed aspects of integrated energy and environment models were considered, namely:

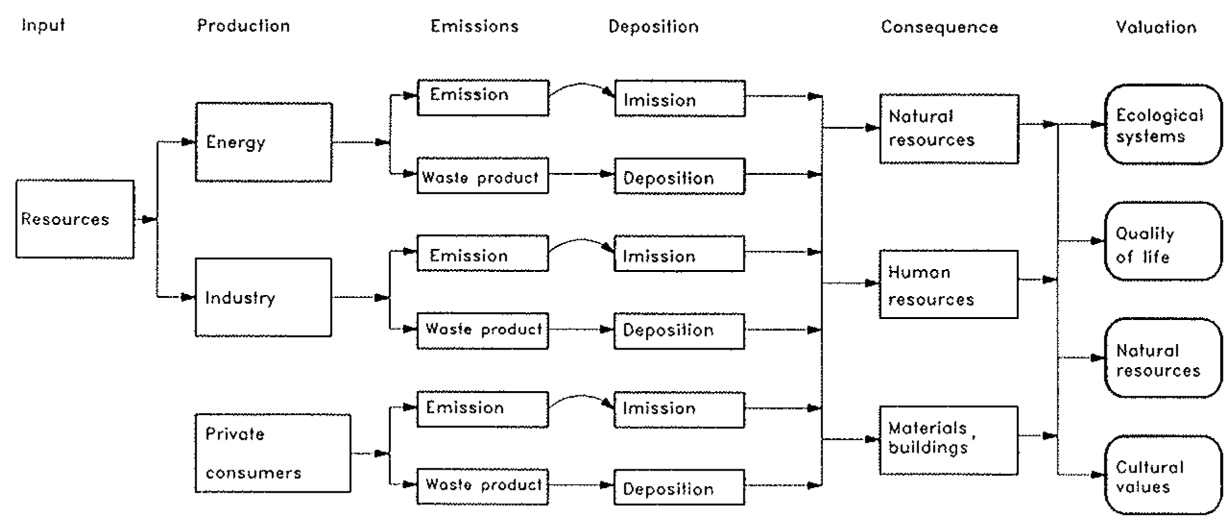
1. Modelling of consequences of the environmental impacts of energy production and consumption.
2. Comparison of environmental effects of different energy systems.
3. Environmental impact assessment.
4. Policy instruments.

A main conclusion of the review was that further methodological improvement and use of models are particularly needed in two areas:

- Treatment of multicriteria planning restrictions for different kinds of environmental impacts such as acidification, health damage and damage to the ecosystem.
- Modelling of links between different kinds of economic growth strategies and environmental consequences in order to show possible development paths following the idea of "sustainability", which was recommended by the Brundtland Commission.

Work is now continuing on clarifying these areas. This includes scientific cooperation with the main centres for integrated energy and environmental modelling in the Nordic countries. One result of this work is the holding of a Nordic workshop on integrated energy and environmental models at Risø in February 1990.

Figure 4.3. Schematic diagram of the energy system from resources to consequences



4.9. Space Heating Investments and Emission Reductions

Flue gases emitted to the atmosphere from space heating equipment consist of many chemical components. The combination and concentration of pollutant substances depend on the fuel and type of combustion used in the heating systems. In general, reduction of the emissions can be achieved by lowering the net energy demand in the buildings, improving heating system efficiencies, changing to a different type of heating system, substituting less polluting fuels, or applying purification methods to the fuels prior to use or following combustion.

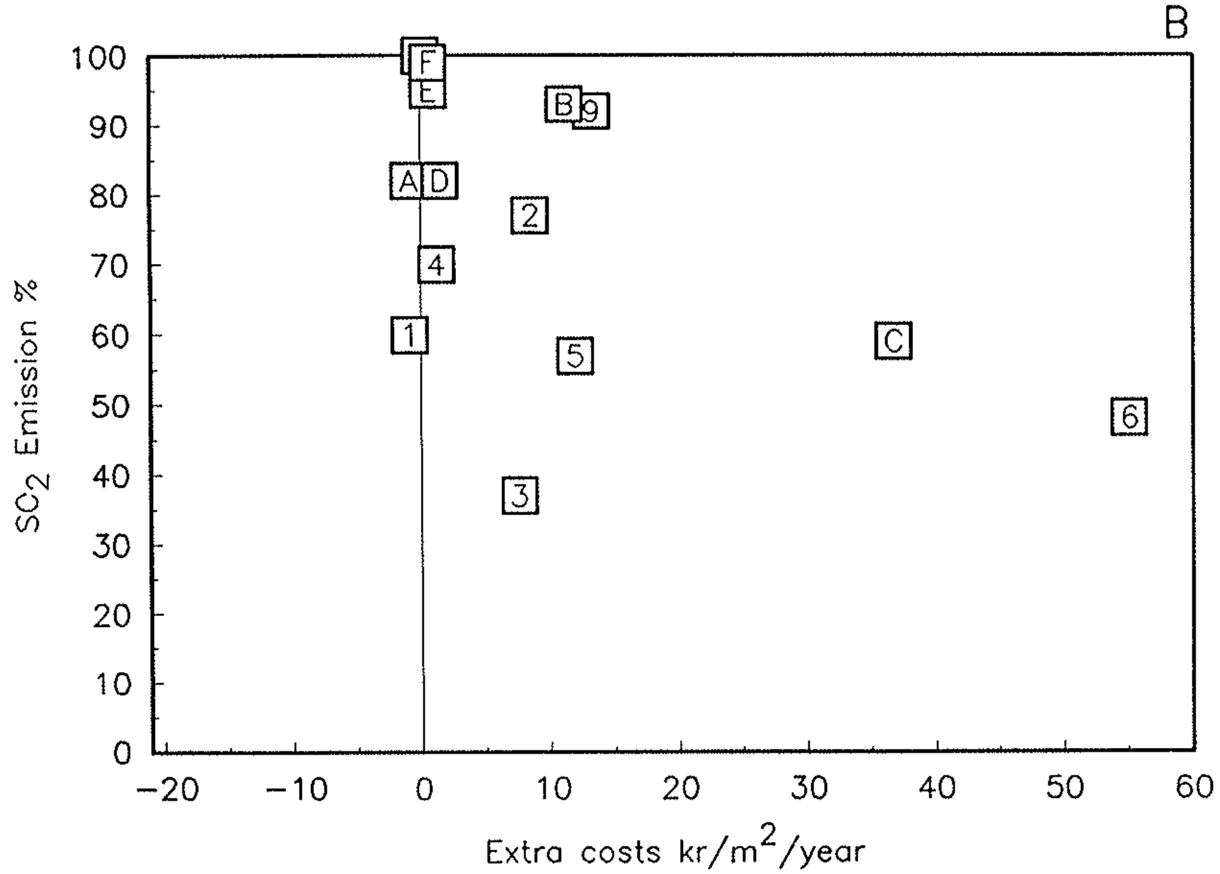
In 1988 a project was initiated in the Systems Analysis Department aimed at studying the effects of various measures for reducing emissions in the space heating sector. As part of this project a model has been developed to analyse the economic and technical possibilities for achieving emission reduction.

The project report (Christensen et al 1989c) focused on emissions of SO_2, NO_x, PAH, and CO_2. The report presents an overview of emissions, fuel consumption, etc. of the Danish building stock in 1988 split up according to building categories and heating systems. Emissions are calculated on the basis of gross floor area, net energy demand, heating system efficiencies and emission factors. Corresponding quantities are presented per m^2 gross floor area and year.

Emission reduction costs are analysed for typical single family dwellings which represent different insulation levels in the building stock corresponding to building regulations in force in various time periods prior to 1979. These building categories have been analysed with regard to the specific heating systems installed. Particular attention is paid to retrofit insulation options in dwellings heated by individual oil-fired central burners or electrical resistance.

Figure 4.4 illustrates the type of results that can be generated by the model. The figure shows average annual SO_2 emissions and costs for a number of alternatives. The reference situation has zero investments and zero extra costs.

Figure 4.4. Average annual SO_2-emissions corresponding to various energy conservation measures. The dots represent specific retrofit insulation alternatives applicable to typical single family houses constructed according to the building regulation code in force in 1970. The results are for houses with oil-fired central heating.



The second phase of the project was devoted to the development of a version of the model which could be used as a planning tool at the local community municipal level. This model contains a calculation structure for analysing scenarios of the building stock, where new buildings, demolition of buildings and reconstruction and retrofit of buildings are taken into account along with such things as changes in heating systems. Economic consequences seen from the point of view of the consumer have furthermore been incorporated as well as those from the planning point of view.

A planned third phase of the project will aim at implementing and testing the model in a municipality.

The project was supported by the Danish Building Agency and the Danish Energy Agency.

4.10. CORINAIR

CORINAIR is a programme of the Commission of the European Communities aimed at establishing a database on emissions of atmospheric pollutants in all the member states. Atmospheric emissions are transboundary in nature and a common, transparent, and coherent set of data for the European nations is essential for qualified evaluation of the origin, transport, and deposition of pollutants.

The database has been established in accordance with the following principles:

The inventory

- is on a yearly basis,
- comprises a number of pollutants,
- quantifies some seventy polluting activities,
- includes seven different fuels,
- is separate for large point sources or other "area" sources, and
- attributes the origin of the emissions to administrative units the size of Danish counties.

The project is organised by a central team in DGXI and national experts who are responsible for all data in their country.

The immediate objective of the project was the establishment of a European database for 1985. This was achieved in 1989 and publication is now in progress.

Figures 4.5(a),(b), and (c) show summary sheets for Denmark for the three pollutants which have been included up to now. Similar sheets are produced for all states, regions, and counties in the European Community.

The CORINAIR programme will be continued and expanded during the next few years and will eventually be monitored by the European Environmental Agency.

4.11. Sewage Treatment Plant

In 1988 a project was initiated to attempt to solve certain energy-related problems that occur in sewage treatment plants in winter. The project is being carried out in collaboration with I. Krüger A/S and financed under the Danish Energy Research Programme 1988 (EFP 88).

Until now there has been a lower level of nitrification at temperatures below 8°C. It is expected, however, that demands for nitrification in sewage treatment in winter will be made more stringent in the coming years. Bacteriological nitrification which will be used in the majority of plants almost ceases at temperatures below 6°C; one result of this is that nitrogen concentration limits in effluent water are exceeded.

In order to deal with this problem greater knowledge is required on how existing plants function in winter. There is a need for technical-economic evaluation of the various modifications, extensions, and alternative processes which could be introduced in order to find the most economical way of dealing with the problem.

The first part of the project has been a measurement programme for the winter 1988/89 covering fourteen plants of varying sizes, constructions, and types of sewage systems. Unfortunately, the water temperature did not drop below 6°C during the winter, and the measurement programme is therefore being reactivated during the winter 1989/90. Four of the fourteen plants involved are covered in detail by datalogging and a water analysis programme. The collected data will form the basis for the subsequent analysis.

4.12. The Great Belt Fixed Link: Energy and Emissions

In 1987 it was decided by the Danish parliament to build a fixed link for road and rail traffic across the Great Belt, the wide stretch of water that separates the heavily populated island of Zealand from western Denmark. Parts of the link are already under construction and the entire link is expected to be completed in 1993 for rail traffic and three years later for motor traffic.

CORINAIR — DK 1985 — EMISSIONS OF POLLUTANTS

Date calcul : 26/01/90 EDITED 22/02/90

TERRITORIAL UNIT : DENMARK 0000000

POLLUTANT: SULPHUR DIOXIDE SO2

UNIT : (Mg/y)

GROUPS OF ACTIVITIES	AREA SOURCES	POINT SOURC.	TOTAL
Combust. energy generation	79781	161605	241386
Oil refinery	0	3949	3949
Combustion in industry	61382	0	61382
Industrial production	15200	504	15704
Solvent evaporation	0	0	0
Road transport	11164	0	11164
Nature	0	0	0
Miscellaneous activities	0	0	0
T O T A L	167527	166058	333585

CORINAIR — DK 1985 — EMISSIONS OF POLLUTANTS

Date calcul : 26/01/90 EDITED 22/02/90

TERRITORIAL UNIT : DENMARK 0000000

POLLUTANT: NITROGEN OXIDES NOX

UNIT : (Mg/y)

GROUPS OF ACTIVITIES	AREA SOURCES	POINT SOURC.	TOTAL
Combust. energy generation	20337	128305	148642
Oil refinery	0	1620	1620
Combustion in industry	12738	0	12738
Industrial production	4029	730	4759
Solvent evaporation	0	0	0
Road transport	102831	0	102831
Nature	0	0	0
Miscellaneous activities	0	0	0
T O T A L	139935	130655	270590

CORINAIR — DK 1985 — EMISSIONS OF POLLUTANTS

Date calcul : 26/01/90 EDITED 22/02/90

TERRITORIAL UNIT : DENMARK 0000000

POLLUTANT: VOLATILE ORGANIC COMPOUNDS (incl. CH4) VOC

UNIT : (Mg/y)

GROUPS OF ACTIVITIES	AREA SOURCES	POINT SOURC.	TOTAL
Combust. energy generation	13231	789	14020
Oil refinery	0	3285	3285
Combustion in industry	1635	0	1635
Industrial production	1809	0	1809
Solvent evaporation	58469	0	58469
Road transport	96459	0	96459
Nature	7102	0	7102
Miscellaneous activities	25008	0	25008
T O T A L	203713	4074	207787

Figure 4.5. Output from the CORINAIR database showing summary of emissions for Denmark of (a) SO_2, (b) NO_x, (c) Volatile organic compounds (VOC).

A preliminary study of the consequences for energy consumption and airborne emissions associated with the transfer of traffic from ferries to the fixed link was carried out by the Systems Analysis Department in 1988. This study concluded that an energy saving of 2-3 PJ could be expected in 1996, along with small reductions in emissions.

The study has recently been followed up by a more detailed one in which more attention was paid to the broader changes which are expected to occur as a consequence of the opening of the fixed link. A major part of the study was also concerned with collecting and confirming the most up-to-date information on energy consumption and emissions for the various modes of transport.

In the case of passenger cars, lorries, and freight trains, energy consumption and emissions were calculated on the basis of traffic forecasts for 1996. For passenger trains and ferries, on the other hand, the calculation was based on the planned schedule of passenger trains and ferry crossings, respectively. The opening of the fixed link will in fact be accompanied by a substantial increase in intercity passenger rail services, made possible by the Great Belt connection. The calculation therefore takes account of the difference in total energy consumption between the two intercity timetables for the whole country, before and after the opening of the link.

The calculations were made for two situations or scenarios: (a) the fixed link for both road and rail in 1996, and (b) no fixed link is built and the ferry link between east and west is maintained. In the latter case, the present separate rail and car ferries are replaced by combined ferries. It is assumed that this combined ferry service would be based on the present intercity rail ferries, so the energy consumption for a crossing is already well-known.

In addition to the road traffic associated with the actual crossing, the calculation also includes the extra distance involved when taking into consideration the expected 26% increase in east-west road traffic. This increase consists of trips which otherwise would never have taken place at all; therefore, the total distance associated with these trips is the average length of an east-west trip, about 200 km, rather than simply 20 km over the fixed link. A similar extra distance is added for traffic which is rerouted from other ferry routes, that takes the fixed link despite the extra distance because of the time saved.

The result of the latest calculation was that a total energy saving of 2.3 PJ could be expected in 1996 compared with a situation in which the crossing was done by combined rail and car ferries Small changes in emissions can also be expected, mainly reductions, but these are relatively unimportant compared with the total emissions of the energy sector in Denmark, as can be seen from Table 4.1.

The results are naturally subject to a number of assumptions concerning both the magnitude of traffic in 1996 and the composition and technical details of the various modes of transport. These factors introduce an uncertainties in the final results. To explore this we have performed sensitivity analyses which have shown that the results are very robust, even with respect to large variations in the parameters.

The study has thus shown that in all probability the opening of the fixed link will lead to a slight reduction in energy consumption and an insignificant reduction in emissions from the transport sector.

Table 4.1. Changes in emissions expected on the opening of the fixed link in 1996 compared with total emissions in Denmark (1987 level)

	CO	HC	NO_x	SO_2	Particles	CO_2
Total emissions (DK) in 1987 (1000 tons)	–	–	262	249	–	64134
Emission from DK transport sector in 1987 (1000 tons)	530	63	91	11	8	9179
Emission reduction in 1996 (1000 tons)	– 0.98	0.12	1.53	1.33	0.18	165
% of total emissions	–	–	0.6	0.5	–	0.3
% of transport sector emissions	– 0.2	0.2	1.7	12.1	2.3	1.8

Table 4.2. Wind turbines erected in Denmark and exported.

	Erected in Denmark				Exported		
Year	Number	Capacity (MW)	Accumulated capacity (MW)	Turnover (Mill.DKK)	Number	Capacity (MW)	Turnover (Mill.DKK)
1976-78	50	2	2	–	–	–	–
1979	120	2	4	–	–	–	–
1980	200	5	9	25	–	–	–
1981	220	7	16	50	30	0.4	4
1982	150	7	23	50	50	1.0	10
1983	100	4	27	35	360	20	200
1984	150	8	35	80	1600	110	1000
1985	314	25	60	200	3000	200	2000
1986	320	30	90	250	2000	170	1200
1987	300	35	125	200	–	–	400
1988	300	45	170	250	–	–	250

4.13. Wind energy

Within the past 10 years the market for wind turbines has increased considerably. Today more than 2000 Danish-built units, mainly generating electrical energy, are installed in Denmark and the installed capacity exceeds 170 MW. Table 4.2 shows the development.

At the beginning of the 80s most wind turbines sited in Denmark were rated at 55 kW. Since then the sizes of the units have increased substantially as shown in the table. Nowadays, the most commonly erected turbine has a rated power of 100-250 kW, and even larger sizes are marketed. Table 4.3 shows a typical cost breakdown of a 250-kW wind turbine.

Table 4.3. Cost breakdown of a 250-kW wind turbine (1989 Danish crowns).

	Cost (1000 DKK)
Turbine ex works	1045
Foundation	90
Installation	25
Grid connection	200
Rental of land	20
Miscellaneous incl. consultancy fees	40
Total	1420

The uncertainties for each of these estimates of cost components are unequal. In order to improve the basis for the calculation of the costs of wind produced electricity, Risø caried out a survey in 1988.

The aim of the survey was to obtain actual figures for investment costs, repairs and maintenance, annual electricity production, social and environmental effects, special problems, that arose etc. More than 800 questionnaires were sent out, and slightly fewer than 40% responded.

One of the main results of the survey was to establish the relationship between individual cost components. This relationship is shown in Table 4.4.

As seen from Table 4.4, the relationship across vintages of turbines seems to be fairly stable. The total investment costs of the turbine are approx. 30% above the turbine price ex works, i.e. approx. 23% of total investment costs are due to foundation, installation/grid connection, and miscellaneous (including consultancy). The share of foundation is very stable at around 9% of the price ex works, while the installation/grid connection varies between 14 and 20% of the price ex works. Concerning prices of the turbines themselves, variations are small.

Using the data for all the relevant costs for wind turbines in the survey, Figure 4.6 shows total average costs per produced kWh for each vintage of turbine.

Table 4.4. Relationship between cost components of wind turbines in percentages of the price ex works.

Vintage	Total price %	Installation and grid connection %	Foundation %	Miscellaneous %
1980	130.0	18.2	9.0	4.8
1981	131.8	19.4	9.6	6.5
1982	131.2	18.7	8.8	4.3
1983	130.0	17.7	9.1	6.0
1984	125.3	14.4	9.0	3.0
1985	127.6	14.9	9.0	3.1
1986	127.9	15.5	9.1	4.7
1987	129.4	16.5	9.6	3.6
1988	130.6	19.9	8.6	3.9

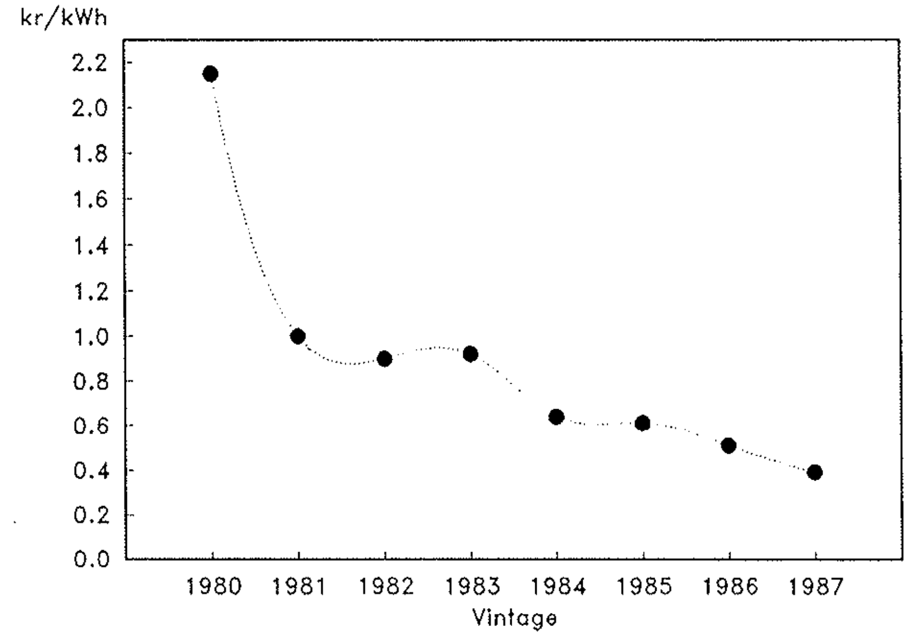
Calculations are performed using actual investment costs, levellized with a real interest rate of 7% at a lifetime of 20 years, adding actual operation and maintenance costs and dividing by the actual electricity production by the wind turbine in 1987 (corrected for the energy content in the wind). This gives the actual costs per kWh-produced in the year 1987. For comparison, all figures are inflated to 1988 levels in Figure 4.6. It should be noted that there is only one observation made for the year 1987, which means that this figure is not statistically significant.

The tendency towards lower costs per produced kWh for new vintages seems to be due to several factors:

- lower capital costs for new wind turbines,
- improved efficiency and siting of new turbines,
- higher reliability for new vintages
- increasing operating and maintenance costs during the lifetime of a windturbine, and
- higher operating and maintenance costs for older vintages of turbines.

The survey does not give the final answer with regard to operating and maintenence costs. More work is needed in the future to clarify how these costs increase as the machine ages.

Figure 4.6. Average costs per produced kWh for the year 1987 for different vintage of wind turbines (1988-prices).



5. Conferences, Publications and Lectures

5.1. Conferences

In 1989 the department organised an international conference on Environmental Models: Emissions and Consequences. The conference sponsored by the Commission of the European Communities, took place 22-25 May at Risø. It aimed at bringing together scientists, economists, and decision makers with a mutual interest in the planning of emission reductions and alleviating environmental damage. It addressed both the basic scientific aspects of model development and experience with practical applications of environmental models, e.g. in public planning and administration.

The conference was organised in a number of sessions dealing with: emissions, emissions and short-range effects, economics, biological effects, aquatic systems, terrestrial systems, integrated models, and energy and environmental planning.

There were 40 oral presentations, of which three were invited keynote papers. In addition, a number of papers were presented at a poster session. The session on energy and environmental planning was given special attention with 12 oral presentations.

The emissions dealt with were all substances directly harmful to plants, animals, and human beings. Focus was put on models describing the impact of different pollutants, and the quantification of environmental consequences, both in physical, biological, and economic terms.

The conference attracted 120 participants from 20 different countries mostly from western Europe along with Poland, Jugoslavia, USSR, USA, Japan, and Canada. The conference proceedings containing the full oral presentations have been published by Elsevier Science Publishers, Amsterdam, where they may be purchased.

Conference participants outside the Niels Bohr Auditorium at Risø.

5.2 Publications

Andersen, F. Møller (1989). The HERMES-Model for Denmark. Risø-M-2800, 157 pp.

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Christensen, P.S. (1989). The DESS System. User's Guide. Release 1.4. (Risø National Laboratory, Denmark. Unpublished available on request from Systems Analysis Department). 69 pp. + Appendix (update June 1989).

Christensen, P.S., Grohnheit, P.E. (1989a). The DESS System. Release 1.4. Source program for VAX and IBM computers with test and demonstration examples. (Risø National Laboratory, Roskilde. Unpublished available on request from Systems Analysis Department). 2 Mbytes on disk.

Christensen, P.Skjerk, Petersen, S. (eds) (1989b). Risøs indsats i forbindelse med Energiministeriets forskningsprogrammer. Status ultimo december 1988. (The contribution of Risø National Laboratory to the research and development programme of the Danish Ministry of Energy). Risø-M-2767, 83 pp.

Christensen, P.Skjerk, Halsnæs, K., Nielsen, L.H., Sørensen, H. (1989c). Varmesektorens emissioner og emissionsreduktionsmuligheder ved efterisolering af enfamiliehuse (Emissions from the Danish building stock and emission reduction from retrofit insulation of dwellings). Risø-M-2808, 111 pp.

Christiansen, H. (1989). Modellering af tungmetaller i jord (Modelling heavy metals in soils). Risø-M-2766, 42 pp.

Christiansen, H., Danielsen, E., Jørgensen, K., Mackenzie, G.A. (1989). Miljømæssige aspekter: EDB-model vedrørende miljøeffekter ved energiproduktion (Environmental aspects: Development of a computer model for environmental input of energy production). Risø-M-2765, 50 pp.

Fenhann, J. (1989). Emissioner af SO_2, NO_x og CO_2 fra det samlede danske energisystem. 1975-1988 (Emissions of SO_2, NO_x and CO_2 from the total Danish energy system 1975-88). Forskningscenter Risø, Energisystemgruppen, Roskilde, 46 pp.

Fenhann, J., Halsnæs, K. Emissions of SO_2, NO_x and CO_2 from the Danish energy sector in the period 1975-2000; In: Vidal, V., Straszak, A., Ravn, H. (eds). Proceedings of the conference on the systems analysis approach to environmental and natural resources management in the Baltic region, 26-29 September 1988. IMSOR, Danmarks Tekniske Højskole, Lyngby, 12 p.

Grohnheit, P.E. (1989a). Grænseoverskridende luftforurening (Transboundary air pollution). Miljøøkonomi i Norden (no. 2), p. 19-21.

Grohnheit, P.E. (1989b). The DESS Model: A Detailed Energy System Simulation Model for the EC Countries. Risø-M-2809, 39 pp.

Halsnæs, K. (1989). Energiplanlægning og miljø. Kortlægning af værktøjer og metoder til integreret energi- og miljøplanlægning i de nordiske lande (Energy planning and the environment, investigation of means and methods to achieve integrated energy and environmental planning in the Nordic countries). Forskningscenter Risø, Systemanalyseafdelingen, Roskilde (NORD, 51) 70 pp.

Halsnæs, K. (1989). Problemer i modelleringen af energisystemets miljøpåvirkning (Problems in the modelling of environmental input of the energy system). In: SVANE JØRGENSEN, M., HOMANN JESPERSEN, P. (eds.) Modelbygningsforsøg, systemteori og miljøplanlægning. Forskningsrapport serie 11, Roskilde Universitetscenter 1989, 10 pp.

Halsnæs, K., Sørensen, H. (1989). Simulation of the Italian energy system with the DESS-Model. Risø-M-2798, 69 pp.

Kilde, N., Madsen, M. (1989). Indpasning af større absorptionskølemaskiner i det danske energisystem (How to fit absorption cooling into the Danish energy system), Risø-M-2773, 74 pp.

Larsen, H.V. (1989). Beskatning i forbindelse med efterforskning og udvinding af kulbrinter i den danske undergrund (Taxation related to exploration and extraction of hydrocarbons in Denmark). Risø-M-2841. 63 pp.

Larsen, H.V., Fenhann, J., Præstegaard, S. (1989). Simuleringsmodel for produktion og lagring af el og varme (Simulation model for electricity and heat production). Forskningscenter Risø, Systemanalyseafdelingen. 66 pp.

Petersen, K.E. (1989). Deliverability of the Danish Natural Gas System. In: Reliability Data Collection and Use in Risk and Availability Assessment. 6th EuReDatA Conference, Siena, Italy, 15-17 March 1989. (European Reliability Databank Association). Session 5, 13 pp.

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Petersen, K.E. (1989). Sikkerhedsanalyse af danske imprægneringsanlæg. (Safety Analysis of Danish Vacuum Pressure Impregnation Plants). In: Nordiske Trebeskyttelsesdager 1989 (Nordic Wood Treatment Workshop), Hamar, Norway, 7-8 September 1989. (Nordisk Trebeskyttelsesråd) 6 pp.

Petersen, K.E., Rasmussen, B., Jensen, P.H. (1989). Reliability Analysis in Life Cycle Cost Estimation for Small Windturbines. In: Reliability Achievement, The Commercial Incentive, Stavanger, Norway, 9-11 November 1989. Ed. by T. Aven (Society of Reliability Engineers, Scandinavian Chapter) 9 pp.

Petersen, K.E. (1989). Risikoanalyse Automatiserede Systemer eller Manuel Styring. (Risk Analysis Automatic Systems or Manual Control). In: Sikkerhed versus organisation, teknik og (efter)uddanelse. (Safety versus Organization, Hardware and Education), Lyngby, Denmark, 25 October 1989. (Danish Automation Society), 11 pp.

Petersen, K.E., Poucet, A. (1989). Knowledge Based Tools for Reliability/Risk Analysis and Maintenance Planning. In: American Institute of Chemical Engineers 1989 Annual Meeting, San Francisco, USA, 5-10 November 1989. (American Institute of Chemical Engineers). Session 26, 15 pp.

Rasmussen, B., (1989). Chemical Process Hazard Identification. Reliability Engineering and System Safety, 24, p. 11-20.

Rasmussen, B., Smith-Hansen, L. (1989). Cost-Effective and Uniform Procedure for Performing Risk Analysis of Similar Chemical Plants. In: Loss Prevention and Safety Promotion in the Process Industries. Vol. 2. 6. International Symposium, Oslo, 19-22 June 1989. (European Federation of Chemical Engineering) p. 66.1-66.12.

Systemanalyseafdelingen (1989). Storebælt: Energi og emissioner (The Great Belt: Energy and Emissions). (Forskningscenter Risø/A/S Storebæltsforbindelsen) 54 pp.

5.3. Lectures

Fenhann, J., Halsnæs, K. Long-term growth scenarios for the Danish energy system according to the need for a sustainable development. International workshop "Environmental management in the Baltic Region: Monitoring, Modelling, Analysis". Leningrad, 21-24 November 1989.

Fenhann, J. Developments in energy modelling, International course on rural energy planning. 14 June 1989, University of Twente, Netherlands.

Fenhann, J. Long-term energy scenarios for Denmark and sustainable development. Institute of Economics, Academy of Sciences of Estonian SSR, Tallinn, Estonia, 28 November 1989.

Grønberg, C.D. Danes at Risk. 8 August 1989. Nordic Accident Research Seminar NOFS-89, Nurmes, Finland.

Halsnæs, K. Danmarks Tekniske Højskole, Fys. Lab. III. Metoder til energi og miljøplanlægning (Methods for energy and environmental planning). 13 October 1989.

Halsnæs, K. Integreret energi- og miljøplanlægning (Integrated energy and environmental planning). Seminar on decision support systems organised by Risø National Laboratory, Danish National Environmental Research Institute and the Local Government Research Institute on Administration and Finance, 12-13 December 1989.

Juhl Thomsen, N. Udredning om energiforbruget til procesformål. (Industrial energy consumption). Technical seminar on the preparation of the Danish energy action plan). Eigtveds Pakhus, København. 22 November 1989.

Kilde, N.A. The Danish participation in the CORINAIR programme and the use of CORINAIR and COPERT software. 30 November-1 December 1989. Scandinavian symposium on the CORINE programme. Skov- og Naturstyrelsen, Hørsholm.

Larsen, H. Risøs arbejde vedrørende beslutningsværktøjer (Decision support model development at Risø). Seminar on decision support system organised by Risø National Laboratory, Danish National Environmental Research Institute and the Local Government Research Institute on Administration and Finance, 12-13 December 1989.

Larsen, H. Fremtidens energisystemer (Future Energy Systems). Scanticon, Helsingør, 7 October 1989.

Morthorst, P.E. Den udviklede scenariemodel i forbindelse med energihandlingsplanen. (The Brundtland Energy Scenario Model). Technical seminar on the preparation of the Danish energy action plan. Eigtveds Pakhus, København. 22 November 1989.

Nielsen, M., Ott, S., Smith-Hansen, L. Udslip og spredning af gasser (Release and Dispersion of Gases). 27-28 November 1989, University of Lund, Sweden.

Nielsen, S.N. Recent Development in Structural Dynamic Models. Risø International Conference on Environmental Models: Emissions and Consequences. 22-25 May 1989.

Nielsen, S.N. Application of Exergy in structural-dynamical modelling. XXIV Congress of the International Association of theoretical and applied Limnology. August 13-19, 1989. Munich, Federal Republic of Germany.

Petersen, K.E. 2 guest lectures at Technical University of Denmark course on "Reliability Theory". 7 December 1989: Usikkerhed og menneskelige fejl (Uncertainty and Human Errors). 11 December 1989: Beslutningsstøttesystemer og pålidelighedsanalyse (Decision Support Systems and Reliability Analysis).

Rasmussen, B. Uønskede kemiske reaktioner (Unwanted chemical reactions). 11 April 1988. The Technical University of Denmark.

Rasmussen, B. Risikovurdering (Risk assessment). 30 May 1989. Arbejdstilsynet (Danish Labour Inspection Service).

Rasmussen, B. Risikovurdering (Risk assessment) 1 June 1989. Sammenslutningen af sikkerhedsledere i Danmark.

Rasmussen, B. Driftspålidelighed (Reliability) 13 October 1989. Københavns Teknikum.

Rasmussen, B. Risikovurdering (Risk assessment). 27 October 1989. Københavns Teknikum.

Rasmussen, B. Risikoanalyse af kemiske procesanlæg (Risk analysis of chemical process plants). 2 November 1989. Dansk selskab for teknisk arbejdshygiejne.

Schleisner, L. Aquifer thermal energy storage, status and future prospects. The second world congress on heating, ventilating, refrigerating and air conditioning, Clima 2000. 26 Aug.- 1 Sept. 1989.

Schlesiner, L. Udredning om el- og varmeproducerende varmeproduktionsteknologier (Power and heat production technologies). Technical seminar on the preparation of the Danish energy action plan. Eigtveds Pakhus, København, 22 November 1989.

Smith-Hansen, L. Et eksempel på risikorådgivning. Risikoanalyse af et kemisk anlæg (An example of risk advising. Risk Analysis of Chemical Plant) 9 February and 18 May 1989, Seminars on fire and the environment arranged by Dansk Brandværnskomite (Danish Fire Protection Association).

5.4. Participation in Committees etc.

The Department is represented in a number of national and international committees, steering groups etc. Examples of these are:

Danish

1. Research committee for industrial processes and products (Min. of Energy).
2. Steering group, scenarios for energy consumption in transport.
3. Electricity forecasting group (Min. of Energy).
4. Steering group, Staff Training and Institutional Strengthening (Danish Energy Agency)
5. Inter-ministerial committee on energy policy in the EC (Min. of Energy).
6. Export coordination committee (Min. of Energy).
7. Risk assessment committee (Academy of Technical Sciences).
8. Steering committee, Danish Society for Risk Assessment.
9. Environmental Appeal Board.
10. V.E. data.
11. DIF's udvalg vedr. norm for risikoanalyse (Committee on standards for risk and reliability analysis, Danish Society of Chemical, Civil, Electrical, and Mechanical Engineering).
12. Working group on energy use in buildings (Min. of Energy).

International

1. Ad hoc expert group on energy systems analysis (Commission of the European Communities).
2. CGC5 Nuclear fission energy, safety (C.E.C.).
3. Steering committee, Society of Reliability Engineers, Scandinavian Chapter.
4. Steering committee, European Safety and Reliability Association.
5. Editorial board, Journal of Loss Prevention in the Process Industries.
6. RAS/NKA Steering committee.
7. International Programme Committee for the conference on "The systems approach to environmental and natural resources management in the Baltic region", Leningrad, November 1989.
8. Scientific Advisory Panel, First International Conference on Loss of Containment.
9. Editional board, Nuclear Instruments and Methods, Section A.
10. Committee for European Standards on Nuclear Electronics.
11. International Programme Committee for the Conference "Yu-7 on Reliability and Maintainability" June 1990, France.
12. International Organizing Committee for the Conference "REL'-91; Reliability 91", June 1991, UK.

6. STAFF

Hans Larsen, M.Sc. (Elec. Eng.), Ph.D. in reactor physics. From 1973 to 1976 at Dragon project at AEE Winfrith, U.K. Risø from 1976. Energy Technology Department 1976-80, working with systems reliability. Head of Energy Systems Group 1980-84. Head of Systems Analysis Department from 1985.

Energy Systems Group
Niels Juhl Thomsen, M.Econ. Danish Ministry of Education 1978-79, Danish Ministry of Housing and Building 1979-81, Danish Ministry of Energy 1981-89. Joined Risø as Head of Energy Systems Group in May 1989.

Jørgen Fenhann, M.Sc. (Physics with mathematics and chemistry). Niels Bohr Institute 1977. Risø from 1978. Main activities: Development of energy planning models, economics of new and renewable energy technologies, calculation of emissions from energy system, and energy planning for developing countries. Deputy head of Energy Systems Group.

Frits Møller Andersen, M.Econ. Specialized in econometrics and macro-economic modelling. Research assistant Århus University 1978. Assistant planner in local government 1979. Risø from 1980. Main activities: The macro-sectoral model HERMES for Denmark and a technical-economic model for the Danish industrial energy consumption.

John Møbjerg Christensen, M.Sc. (Eng.), Ph.D. National Agency of Technology 1980-83, R&D initiation and administration for Council of Technology, Oilconsult 1983-84, R&D Energy Planning. Risø from 1984 until 1988. From August 1988 on leave from Risø, working as Programme Officer in the Energy Unit of United Nations Environmental Programme headquarters in Nairobi, Kenya.

Peter Skjerk Christensen, M.Sc. (Elec. Eng.). Risø from 1958. Nuclear research and education (1958-69), reactor engineering and thermohydraulics including simulation models (1969-76), Energy Systems Group from 1977. Main activities: Energy systems modelling.

Poul Erik Grohnheit, M.Econ. Danish Building Research Institute 1969-71, town planning consultant 1971-72 and 1979-80, budgetting and economic planning in local government 1973-79. Risø from 1980. Main activities: Energy system and environmental modelling, and economics of power plants.

Kirsten Halsnæs, M.Econ. Danish Ministry of Housing and Building 1983-87. Risø from April 1987. Main activities: Nordic collaboration on integrated energy and environmental planning, integrated models, environmental economics.

Lotte Schleisner Ibsen, M.Sc. (Mech. Eng.). Risø from 1984 in Research Section of the Engineering Department working on aquifer thermal energy storage. Joined Energy Systems Group in 1989. Main activity: Assessment of energy technologies.

Niels A. Kilde, M.Sc. (Chem. Eng.). The Danish Steelworks Ltd. 1962-81. Research and quality control (1962), planning and administration (1967), casting department manager (1972), development and energy manager (1977). Risø from 1981. Member of the steering group for R&D in industrial processes of the Ministry of Energy. Main activities: Energy use in industry and transport, emissions inventory.

Helge V. Larsen, M.Sc. (Elec. Eng.), Ph.D. Technical University of Denmark 1974. Storno A/S from 1975. Risø from 1976. Department of Reactor Technology 1976-77. Energy Systems Group from 1977. Main activities: modelling of energy systems, economic models for the oil and gas sector.

Michael Madsen, M.Sc. (Mech. Eng.). Technical University of Denmark 1982-83. B. Korsholdt Christensen A/S, Consulting Engineers 1983-87. Risø from 1987 until March 1989. Main activities: Assessment of energy technologies and computer simulation.

Poul Erik Morthorst, M.Econ. Economist specialized in econometrics and macro-economics. Risø from 1978. Head of Energy Systems Group 1985-89. Main activities: General energy planning and modelling with emphasis on electricity demand forecasting, economics of renewable energy technologies, especially wind turbines.

Lars Henrik Nielsen, M.Sc. (Phys., Math.). Risø from 1981. Main activities: Probabilistic methods and model development, technical-economic modelling and assessment of energy technologies, especially renewable energy, emissions calculations.

Risk Analysis Group
Per E. Becher, M.Sc. (Mech. Eng.). Airforce equipment command 1970-71. Department of Energy Technology 1971-84. Risk Analysis Group from 1984. Main activities: Structural reliability, reliability and safety analysis of nuclear plants, and safety analysis of industrial plants. Head of Risk Analysis Group until December 1989.

Kurt Erling Petersen, M.Sc., Ph.D. Risø from 1977. Department of Energy Technology 1977-84. Risk Analysis Group from 1984. Main activities: Development of computer codes for reliability analysis, development of tools for operation and maintenance, and treatment of reliability data. From March 1990 Head of Risk Analysis Group.

Palle Christensen, M.Sc. (Elec. Eng.). Risø from 1962. Electronics Department 1962-86 working on nuclear instrumentation, research instrumentation and reliability projects. Department of Information Technology 1986-88 working on knowledge-based computing. Secretary of Risø's patent council 1973-88. Risk Analysis Group from 1988. Main activity: Development of computer codes for reliability and safety analysis.

Carsten D. Grønberg, M.Sc. (Elec. Eng.). Risø from 1967. Electronics Department 1967-78. Safety Department 1978-83. Risk Analysis Group from 1984. Main activities: Human factors, emergency planning, risk management.

Jens Ole Knudsen, M.Sc. (Chem. Eng.). Risø from 1987. Main activities: Dynamic computer-simulation and physical modelling of release, fire, explosion and dispersion of substances from chemical process plant.

Hans E. Kongsø, M.Sc. (Mech. Eng.). Risø from 1957. Research reactor DR 2 1957-63, Department of Energy Technology 1963-84. Risk Analysis Group from 1984. Main activities: Computer codes for reliability and consequence assessment, and risk assessment of nuclear and industrial plants.

Jens Peter Madsen, B.Sc. (Chem. Eng.). Risø from 1988. Main activities: Computer-simulation and physical modelling of release, fire and dispersion of substances from chemical process plant.

Birgitte Rasmussen, M.Sc. (Chem. Eng.), Ph.D. The Technical University of Denmark from 1981-84. Risø from 1984. Main activities: Risk assessment of chemical plants, chemical process hazard identification, assessment of toxic and ecological effects from releases.

Lene Smith-Hansen, M.Sc. (Chemistry). Risø from 1986. Main activities: Risk assessment of chemical plants, toxic effects from releases, and quantitative assessment of toxic chemical substances from combustion.

Environmental Modelling Group
Gordon A. Mackenzie, B.Sc. Ph.D. (Physics). Guest researcher at Risø 1974-78. Lecturer at Edinburgh University 1978-79. Energy Systems Group from 1980. 1984 to 1987 Energy Adviser/ Deputy Director at Department of Energy, Zambia. From February 1988 leader of Environmental Modelling Group. Main activities: integrated energy/environmental models, energy use in transport, energy in developing countries.

Helle Christiansen, M.Sc. (Pharm.). Risø from 1986. Department of Energy Technology 1986-88. Joined Systems Analysis Department February 1988. Main activities: Development of environmental impact models.

Klaus Haahr Jørgensen, M.Sc. (Chemistry). MLKE-Næstved 1986-87. Risø from 1987. Department of Energy Technology 1987-88. Joined Systems Analysis Department February 1988. Main activities: Development of environmental impact models.

Postgraduate students
Søren Nors Nielsen, M.Sc. (Biol.), Major subject: Aquatic ecology and dynamical modelling of eutrophication processes. Ph.D. Student at Risø from 1989. Subject: Structural dynamical modelling of aquatic ecosystems and application of exergy as optimizing function.

Søren Ott, M.Sc. (Phys., Math.). Risø from 1985. Main activities: Models and computer codes for consequence assessment; real time simulation of blow-downs, plume formation, and gas explosions. Ph.D. student from 1987, subject: Micrometeorological aspects of risk assessment.

Sverrir Sverrisson, M.Econ. Risø from 1985. Main activities: Macro-economics, econometrics and international economics, development, and implementation of the CEC macro-sectoral model HERMES. Ph.D. student from January 1987. Subject: The channels of integration between the industrial and the developing countries.

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Jan Scherfig, University of California Irvine, USA.

Consultant
Peter Laut, Professor, Engineering Academy of Denmark.

Programmers
Maria Sonia Cardenas Alvarado. Born in Chile. Educated programmer 1986 in Denmark. Risø from March 1987. Working on error identification and error analysis models.

Ulla Dollerup Hansen. Educated as programmer 1987. Risø from 1987. Computer programs for consequence modelling, and safety and reliability.

Søren Præstegaard, datanom. Regnecentralen 1973-79. Risø from 1979. Datanom with special subject: Optimization completed 1985 at EDP-school, Copenhagen. Working on simulation models and graphics.

Einar Danielsen. Risø from 1985. Temporarily assigned to Systems Analysis Department. Working on development of environmental impact models.

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Abstract (Max. 2000 characters)

The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1989. The activities may be classified as energy systems analysis, risk and reliability analysis and environmental modelling. The report includes a list of staff members.

Descriptors INIS/EDB

ENERGY MODELS; ENERGY SYSTEMS; ENVIRONMENT; PROGRESS REPORT; RELIABILITY; RESEARCH PROGRAMS; RISK ASSESSMENT; RISOE NATIONAL LABORATORY; SYSTEMS ANALYSIS; TECHNOLOGY ASSESSMENT

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